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PROBLEMS ENCOUNTERED IN THE USE OF LOW HEAD RADIAL GATES

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PROBLEMS ENCOUNTERED IN THE USE OF LOW HEAD RADIAL GATES

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Abstract

Three of the principal hydraulic features of low head radial gates are discussed. These are (1) a general discharge equation, (2) the effect of gate seat location on discharge capacity and pressure distribution along the spillway surface, and (3) side and bottom seals.

I. INTRODUCTION

The radial-type gate originated in France about 100 years ago. 1/ The earliest recorded use was by the French Engineer Poiree on the Seine River in 1853. In the 1860's, another French Engineer, Mongel Bey, used a cast-iron, radial-type gate in the Delta Barrage on the Rosetta Branch of the Nile River. The Poiree gates were 28.7 feet wide by 3.3 feet high; the Delta Barrage gates were 16.4 feet wide by 16.7 feet high with the concave face turned toward the reservoir.

The radial-type gate was patented in the United States in 1886. Since then, this type of gate has become widely used and has grown in size. Three 114 feet wide by 26 feet high gates are used on Horseshoe Dam Spillway near Phoenix, Arizona, and it is proposed to use four 40-foot wide by 52.5-foot high radial gates for reservoir control at the new Glen Canyon Dam.

Radial or Tainter gates are probably the most widely used crest control gates. They are particularly well adapted to crest control because of their simplicity of design, construction, and installation. The overall economy and efficiency of this type of gate result from the radial bearing. The thrust from the waterload is carried to two trunnion bearings where it offers little resistance to the operation of the gate. This action can be compared to the hub of a wheel where all of the force on the rim is transmitted to the center. In lifting the gate, there is some force to be overcome at the trunnion, but the side seals may offer considerable resistance in the form of friction. However, the opening of a radial gate requires less hoist capacity than a slide gate with face bearing. In addition, radial gates are more adaptable for automatic control apparatus.

Another desirable feature of a radial gate is that it needs no gate slots. High head flow past indented slots has in some installations produced cavitation damage to the pier and spillway surfaces. One instance where gate slots were the apparent cause of cavitation to spillway and pier side walls is shown in Figure 1; several other cases have

1/Numbers refer to references in Bibliography at end of paper.

been reported in technical literature. 2/ Preventive action has included the use of gate followers to fill the slots at small gate openings, and the use of offsets in the pier side walls downstream from the slots.

Despite the apparent simplicity and wide use of radial gates, very little seems to be known about their operating characteristics. Specifically, there has been very little information published on the discharge capacity, the effect of gate location on pressure distribution on the spillway face, drawdown produced by flow under the gate, and the type of seals to be used, and other hydraulic problems.

The purpose of this paper is to discuss some of the hydraulic features of radial gates, including the side and bottom seals; to present hydraulic data on some representative gate installations; and to create interest in the remaining problems, with the hope that additional material will be presented by the readers of this paper. Further, it is hoped that the tests described will stimulate hydraulic research on radial gates by those in a position to do hydraulic model or prototype investigations.

Material in this paper has been limited to the so-called low head radial gates used to control flow over spillways. Top seal radial gates, where the normal operating head greatly exceeds the gate height, and the small gates used to control canal flow, are not covered.

II. DISCHARGE CHARACTERISTICS

Discharge Determination

Although the radial gate has been used for regulating flow for over a hundred years, a general method for predicting exact flow quantities has not been derived except for one type of installation. When the gate is used in a flat-bottom, rectangular section and the discharging jet is supported by the flat floor, the flow characteristics are known both from mathematical and experimental analyses. The discharge coefficients derived from these studies have been confirmed by several experimenters and are accurate for their specific purpose. 3/ 4/

Many specific discharge determinations are on record; usually, when a spillway has been model-tested, calibration curves for both free and gate-controlled flow have been obtained. From an analysis of these calibrations, the free flow discharge coefficients for almost any shape of overflow section can be determined. 5/ However, a general equation which will provide the exact discharges for radial-gate-controlled flow is still unpublished.

The lack of a general equation can probably be explained by the many variables that affect the flow pattern. Some of these are

in the spillway approach and include channel width and depth. Other variables include the shape of the spillway profile; the geometry of the gate, including the radius, width, height, trunnion location, and the location of the gate seat; the location, spacing, and type of piers; and the method of determining gate opening and reservoir elevation. The combinations of these variables are almost countless, and the effect of any one of them is difficult to determine from a limited number of investigations.

A brief review of four methods which have been used to determine the flow quantities under radial gates indicates the different approaches used in attempts to obtain a general solution. It should be pointed out, however, that each provides only approximate discharges; if an accurate determination is necessary, either model studies or field calibrations should be made.

The first equation is $Q = 2/3\ CL\sqrt{2g}\left[h_1^{3/2} - h_2^{3/2}\right]$ where "C" is the coefficient of discharge listed as a function of gate opening and reservoir head. The definition of the symbols and suggested values for "C" are shown in Figure 2. From the graph, it is apparent that for h_1/d values less than about 2.2 there is a wide range where "C" can vary by as much as 20 percent. The coefficient curve shown as the heavy line was derived from hydraulic model studies of the spillways listed on Figure 2. The different crest shapes and gate arrangements probably account for some of the spread. However, it is known that where the head on an orifice is small in comparison to the height of the orifice, there is an appreciable difference between the discharge obtained by using an average head and the discharge obtained by taking into consideration the variation in head. Depending on the actual values of the orifice height and head, the differences in discharge may be large or small. Thus, the region below $h_1/d = 2.2$ is a transition region, a region notoriously difficult to evaluate in all hydraulic flow problems.

A second method of determining discharge quantities takes into consideration the angle Θ of lip of gate to horizontal and the angle Δ described by the intersection of a horizontal line through the pivotal point of the gate and the radius of the gate drawn from the same point to the center of the gate when it is in a closed position, Figures 3 and 4. The value of the coefficient of discharge for controlled flow is related to the known coefficient of discharge for free flow for different values of Θ and ratios of gate openings d to depth of flow h_1. Plots for two different values of Θ are shown in Figures 3 and 4. The rate of flow is then obtained by applying the formula

$$Q = CL\left[h_1^{3/2} - h_2^{3/2}\right]$$

where h_1 = vertical distance from crest to water surface
h_2 = vertical distance from bottom of gate to water surface
L = width of gate

The coefficients were derived from the results of many model studies.

The third method is similar to the second in that it relates the controlled flow discharge coefficient to the free flow coefficient, Figure 5. The effect of gate radius, trunnion location, and gate opening is also recognized as having an effect on the coefficient and is evaluated by the parameter $\frac{1}{\sin \theta}$. The values for "C" were obtained from analyses of calibrations of model spillways.

The discharge formula for this method is:

$$Q = CL \frac{1}{\sin \theta} \left[h_1^{3/2} - h_2^{3/2} \right]$$

Values for CL and $1/\sin \theta$ are given in Figure 5.

The fourth method, Figure 6, takes into consideration the crest shape, location of gate seat, the angle θ formed by the tangent to the gate lip and the tangent to the crest curve at the nearest point of the crest curve, and the net gate opening which is the shortest distance from the gate lip to the crest curve. From the geometry of the gate the angle θ is determined and from the curves in Figure 6, a coefficient of discharge is determined. These values for "C" were also obtained from model investigations. The discharge is then computed from the formula:

$$Q = CDL \sqrt{2gH}$$

where Q = discharge in cfs
C = coefficient of discharge
D = net gate opening
L = crest width
H = head to the center of the opening

Table 1 shows Canyon Ferry Dam Spillway discharges computed from the four methods described, compared with the discharges obtained from model and prototype calibrations. The Canyon Ferry Dam spillway is a radial-gate-controlled spillway located on the Missouri River about 17 miles east of Helena, Montana. The spillway was calibrated by model studies in 1953, and field discharge measurements were obtained in 1956. 6/

Table 1

Gate opening*	Head*	Proto Q (cfs)	Model Q (cfs)	Computed Q (cfs)			
				1	2	3	4
3 ft	32.32	4,400	4,450	4,870	4,110	4,060	4,880
6 ft	32.00	8,450	8,400	9,240	8,370	8,270	8,940
10 ft	32.45	13,800	13,750	14,720	14,070	13,980	14,510

*Gate openings and heads are measured vertically above gate seat.

The first and fourth methods give 5 to 11 percent higher discharges than actually measured. The second and third methods give discharges from 2 percent over to 7.5 percent under the measured values. The small gate opening shows a greater variation than the larger openings.

The obvious conclusion that can be drawn from Table 1 is that a satisfactory method for computing the discharge through partially open radial gates has not yet been derived. A method of computing discharges is required which will be in better agreement with model tests and field calibrations. Examination of the four discharge equations shows that in three of them the discharge varies as $h_1^{3/2}$ and in the fourth as $H^{1/2}$. A more nearly correct method might be to vary this exponent with changes in h_1/d. The change from free weir flow to orifice flow, or vice versa, would, thereby, be taken into account. The transition range occurs when h_1/d is less than 2.2, Figure 2. When the ratio is greater than 2.2, true orifice flow occurs. Thus, in the free flow range the exponent for the head in the discharge formula is three-halves; in the transition range, the exponent should vary between three-halves and one-half; for orifice flow, the exponent is one-half.

Effect of Gate Position on Discharge Coefficient

In 1953, hydraulic model investigations were made to determine the effect on pressure distribution along the spillway profile caused by changing the location of the gate seat. 7/

For this study, 5 crests were investigated. With each crest, 4 or 5 gate seat locations were tested. The locations were (1) on the crest, (2) and (3) 6 inches vertically below the crest both upstream and downstream from the crest axis, (4) 12 inches below the crest on the downstream side, and (5) the design gate seat location when it did not correspond to one of the other four.

As a part of these tests, data necessary to compute the coefficient of discharge for several gate openings with each gate location were obtained. The coefficients were computed using the first method described. It was found that when the gate seats either upstream from the crest or on the crest, the coefficient of discharge is higher than when the gate seats downstream from the crest. This was true for all crests; in some cases, the difference was as much as 15 percent.

Some of the difference might be explained by the fact that the head and gate opening were measured from the gate seat instead of the crest. However, the head and gate opening values are the same whether the gate seats 6 inches below the crest in an upstream or downstream direction from the crest. In all cases, the coefficients for the upstream position were always higher. An example of these coefficients is shown in Figure 7.

Conclusions and Recommendations

Four different discharge equations have been used to compute the flow quantities under the radial gates of the Canyon Ferry Dam spillway. The discharge coefficients used in each equation were based on different model studies; each equation placed emphasis on different geometric features of the structure. In one equation, the head was raised to the one-half power; in the others, the head was raised to the three-halves power. The flow quantities obtained from these methods were compared with actual model and prototype measurements; the computed flows were found to vary from the measured quantities by as much as 11 percent.

All of the methods described would probably give discharges sufficiently accurate for design purposes or for discharge determinations where water has little value and a rough estimate of the flow would suffice. However, when it is necessary to have an accurate discharge determination for flood routing or to measure valuable irrigation water, as in the western United States, either a model or prototype calibration is necessary.

An accurate formula could be derived by combining theory and data analysis from coordinated hydraulic investigations on model or prototypes. The amount of existing data available from hydraulic laboratories might provide sufficient material for a preliminary analysis and if these data were supplemented by models specifically designed for discharge studies, the effect of each variable could probably be evaluated. Such models would have to be sufficiently large that changes in the geometry of the gates, piers, and overfall section would make measurable changes in the flow. The crest length should be sufficiently long to allow installation of several piers, and provision should be made to test several crest shapes, pier shapes, and gate sizes. It would be desirable to incorporate an adjustable weir in the model headbay, which would maintain a constant reservoir level to facilitate the flow measurement in the transition range between free flow and orifice flow. Standard measuring devices for determining gate openings, discharge quantities, and heads on the crest would be adequate. With such a model, the effect of any of the variables such as approach depth, pier shape, or trunnion location could be evaluated.

III. PRESSURE CHARACTERISTICS

A standard spillway crest is usually designed to conform to the shape of the lower nappe downstream from a sharp-crested weir. This profile is called the datum shape. 5/ When gates are to be used on the spillway, the same crest shape is used from the upstream face to the gate seat. Downstream from the gate seat, the crest profile is sometimes made to correspond to the theoretical trajectory of a jet flowing from a 1-foot high rectangular orifice at the design head. For the same design head, the crest designed for free flow will be steeper than a crest designed for a 1-foot gate opening.

Several factors other than hydraulic phenomena are usually considered when determining the location of the gate seat. If the gate seats on the crest, the theoretical crest curve will be comparatively flat and the spillway will contain considerably more concrete than is usually needed for stability. If the gate seats below the crest, the profile will be steeper, but a higher gate is necessary to retain the same storage pool. Structural and architectural considerations sometimes dictate the gate seat location. If a bridge spans the spillway, it might be necessary to place the gate downstream from the crest to provide space for the gate lifting mechanism or to provide clearance when the gate is raised. The gate might have to be located downstream to insure that the trunnion will be above the water surface.

Many hydraulic designers believe that when the gate is seated on the crest there is a tendency for the jet to spring free of the crest at high reservoir elevations and small gate openings; this may result in subatmospheric pressures and possible cavitation damage to the spillway. The designers also believe that placing the gate seat downstream from the crest results in the flow being directed downward; the tendency of the jet to spring free of the crest is lessened. However, observations of prototype spillways indicate that cavitation damage to the spillway surface occurs downstream from the region where the control gates have any effect on the flow. No damage to spillway crests in the vicinity of the gates has been found which can be attributed to the crest shape and gate seat location.

A realistic solution to these problems and conflicting requirements is needed. The following discussion may help to clarify the problems.

Effect of Gate Location on Pressure Distribution Along a Spillway Profile

The laboratory investigations used to determine the effect of gate location on discharge coefficients were also used to determine the effect of the gate position on the pressure distribution along the spillway surface. 7/ For the pressure tests, 10 piezometers were installed along the crest profile. One piezometer was placed at each tested gate seat and the others were equally spaced downstream along the spillway profile. The five crests used in the investigation provided a wide range of steepness and gate seat locations.

For convenience, each of the crests will be discussed separately giving a description of the crest and the results of the tests. The crest profiles, datum shapes, piezometer locations, and pressure profiles for representative gate openings are shown on Figures 8, 9, 10, 11, and 12.

Ross Dam, Figure 8. The design gate seat is 4 inches below the crest. The datum shape is slightly steeper than the design shape. A comparison of the design shape and datum shape indicates that the

overfall section from the gate seat downstream was designed from the theoretical trajectory of a jet from an orifice. From the reasoning previously outlined, pressures along the profile should increase when the gate seat is downstream from the design location and reduce when the gate seat is upstream.

The pressure profiles on Figure 8 show that for the same gate openings and heads, the pressures for all gate seat locations downstream from the design gate seat are practically the same. However, when the gate is seated upstream from the crest, the piezometers from the crest down to the second piezometer below the design gate seat showed pressures lower than were obtained for the other gate seat locations. Another trend which may be observed from the pressure profiles is that the zone of subatmospheric pressures moved upstream as the gate seat moved upstream. However, for all gate positions, the downstream piezometer (No. 9) showed pressures near atmospheric.

Altus Dam, Figure 9. The design gate seat is on the crest. The datum shape is the same as the design shape, indicating that the profile was obtained from the lower nappe shape of a sheet of water passing over a sharp-crested weir. According to reasoning, the pressures along the profile should have the highest values when the gate seat is 12 inches below the crest and should become smaller as the seat is moved upstream. The pressure profiles in Figure 9 show this to be true in that for both downstream gate seat locations the piezometers downstream from the gate seat indicate nearly atmospheric pressures for all gate openings. Also, when the gate seats upstream from the crest, the piezometers from the gate seat to Piezometer No. 6 indicate subatmospheric pressures. The piezometers downstream from No. 6 all show near atmospheric pressures. Generally speaking, Piezometers No. 6 through 9 showed nearly atmospheric pressures for all gate seat locations at all gate openings. Piezometers No. 2 through 5 were affected by the gate seat location and the pressure was reduced at each piezometer as the gate seat was moved upstream.

American Falls Dam, Figure 10. The design gate seat is on the crest. The datum shape is considerably steeper than the design shape, indicating that the profile from the crest downstream was obtained from the theoretical trajectory of a jet flowing from an orifice. The pressures should be near atmospheric for small gate openings when the gate is at the design location, for downstream gate seat locations the pressures should be higher, and for upstream locations the pressure should be lower. The pressure profiles on Figure 10 indicate that performance agrees with the reasoning. The only pressures significantly subatmospheric were those at the crest piezometer when the gate seat was upstream from the crest.

Bhakra Dam, Figure 11. The design gate seat is 2.43 feet below the crest on the downstream side. The datum shape is steeper

than design shape. For this crest, the highest pressures should occur with the gate at the design location and they should become successively lower as the seat location is moved upstream. Also, the piezometers should indicate near atmospheric pressures when the gate seats on the crest. The pressure profiles on Figure 11 show this to be essentially true. The piezometers downstream from the gate seat show slight reductions in pressure as the seat is moved upstream and when the gate seats on the crest and upstream from the crest, the pressures are a little above and below atmospheric.

Canyon Ferry Dam, Figure 12. The design gate seat is 6 inches below the crest. The datum shape is steeper than the design shape. The relative shape of the two profiles indicates that the profile downstream from the design gate seat was derived from the theoretical trajectory of a jet flowing from an orifice. Therefore, the pressures downstream from the gate should be near atmospheric when the crest is at the design location, higher when the gate seat is downstream and lower as the gate seat is moved upstream. The pressure profiles on Figure 12 indicate that the pressures increase when the gate seat is downstream from the design seat, and decrease when the gate seat is upstream. However, for gate openings of 8.8 and 23.5 percent of the design head, the pressures downstream from a gate seat are practically the same for any gate seat location.

Conclusions

The pressure tests show that the gate seat location has a minor effect on the profile pressures when the gate seat is on or downstream from the crest. When the gate seats upstream from the crest, there is a sharp reduction in the pressure at the crest, particularly at the small gate openings.

The theory that a gate seat downstream from the crest will give a downward direction to the flow passing beneath the gate seems to be confirmed by these tests. Although the increase in pressure was small, it was noticeable for all crests.

The lowest pressures occurred on the two crests that most nearly corresponded with the datum shapes, Figures 8 and 9, and generally occurred for a gate opening of about 33 percent of the design head. For the other three crests, Figures 10, 11, and 12, the lowest pressures occurred at the smallest gate openings. The lowest pressure recorded was about 20 percent of the design head below atmospheric.

IV. GATE SEALS

Radial gates are usually provided with side and bottom seals. In some installations, the side seal bears against a steel plate embedded in the face of the pier; this provides a smooth surface for the contact and prevents excessive wear of the sealing strip. The bottom seal contacts a metal plate set flush with the spillway surface; a shallow depression about 3/32 by 3 inches in the metal sill plate acts as a seating surface.

In 1952, a limited number of tests were performed in the Bureau of Reclamation Hydraulic Laboratory to determine the effectiveness of the gates seals being used. 8/ Because of limitations in the test rig, sliding of the side seal on the wall plate corresponding to the gate opening or closing was not possible. The seal could be moved in a direction normal to the wall plate, to determine the force required to seat the seal. When the seal seated, leakages were too small to be conveniently measured, so visual observations of the leakage sufficed for the tests.

Two tests were made with each seal. The first test was to determine the lateral thrust per lineal foot of seal. If the lateral thrust was within reasonable limits, the seal was tested in the hydraulic rig to determine its action under pressure.

The lateral thrust tests were made with a wooden mock-up of the clamp plates of a radial gate, Figure 13. The thrust was determined by lifting the seal up and off the laboratory floor with a spring scale and steel bar placed under and perpendicular to the seal axis. The seal was lifted at a point midway between two pieces of paper placed 12 inches apart on the floor under the seal. When the paper could be slipped free, the thrust load on the floor was considered relieved and the spring scale load recorded. The frictional drag was computed from this thrust value.

Belt-type seal. One proposed side seal was made from fabric-reinforced rubber belting. A seal 8 inches wide and 15 feet long was assembled in the wooden mock-up for lateral thrust tests. The lateral thrust was determined for various seal positions. Zero seal position occurs when the space between the end of the gate and the wall plate is three-quarters of an inch. The tests showed that at the zero seal position, the lateral thrust was 16 pounds per lineal foot of seal. This thrust was high; and with the addition of a water-load at a 40-foot head, the frictional drag would be 75 pounds per inch of seal. In view of the high drag, no hydraulic tests were performed.

Belt-type seal with brass shoes. It was decided to investigate the same seal with brass shoes bolted to the belting to reduce the frictional drag, Figure 14A. The lateral thrust at zero seal position for this seal was 158 pounds per lineal foot; but because of the smaller coefficient of friction with the brass shoe, the frictional resistance at a 40-foot head was 34 pounds per inch of seal.

Hydraulic tests showed that when the seal was moved away from the wall plate, the seal shoe slid downstream and remained in flat contact with the wall plate. However, when the gate was moved nearer to the wall plate, the brass shoe did not slide upstream on the wall plate, and the rubber belting buckled. Since this action was independent of the reservoir head, the seal was considered unacceptable.

Molded-type belt seal. As a means of reducing the lateral thrust of the belt type of seal, it was proposed that the belt seal be molded to an angular shape, Figure 14B. The lateral thrust of this seal was negligible at zero seal gap. The frictional drag on the wall plate was computed at about 20 pounds per lineal inch.

Hydraulic tests indicated that the brass shoe did not slip upstream freely as the seal gap was decreased. The seal buckled when the gap was decreased 1/4 inch, and the sealing lip raised slightly from the seat. It was concluded that the seal operation was only fair.

Angle seals. Two types of angle seals were investigated. One was an all-rubber seal, and the second was similar, except that it was fabric-reinforced, Figure 15. The lateral thrust with these seals would depend on how they were mounted on the gate sides. Because of this, tests were performed to determine at what head these seals would seal and unseal for various seal-to-side wall spacing. In addition, identical tests were made for the all-rubber seal with a brass bar on the sealing edge.

For the all-rubber angle seal, without the brass bar, the water head required for sealing at a 1/2-inch gap was 22 feet, while unsealing occurred at an 8-foot head, Figure 16. With the brass bar, these values were 23 and 7 feet. The fabric-reinforced seal sealed at a 19-foot head and unsealed at a 6-foot head. The computed frictional drag for these seals was about 37 pounds per lineal inch without a brass bar and 6.5 pounds per lineal inch with a brass bar.

Although the angle seal with the brass bar appeared to have better sealing and unsealing characteristics, as well as a lower frictional drag, it allowed slightly greater leakage than the all-rubber seal and probably would be less desirable for this reason.

Two seals were made that included rubber-to-metal sealing surfaces and a brass member to reduce frictional drag, Figure 17. The seal with the rubber flaps (Figure 17A) was generally unsatisfactory, since the head required to obtain a water seal at normal gaps was higher than normally found for spillway gates.

The second seal, shown on Figure 17B, incorporated a more stabilized sealing lip. At a 1/2-inch gap, this seal sealed at a 20-foot head and unsealed at a 4-foot head, Figure 18. The frictional drag with this type seal at a 40-foot head and at zero gap is approximately 11 pounds per lineal inch.

Conclusions

Based on the results of these tests and on the computations for frictional drag, a side seal design should include the features listed below. A suggested design incorporating these features is shown in Figure 19.

1. The sealing force should not be dependent on the water head.

2. A rubber to metal seal is preferred to obtain the least water leakage. The portion of the waterload carried by the rubber seal should be low so as to reduce the frictional drag.

3. The heel end of the seal should be mounted so that it will not contact the wall plate and increase the frictional drag.

4. The major part of the seal waterload should be carried through a metal member to the wall plates to minimize the frictional drag of the seal.

Radial Gate Bottom Seal Tests

The hydraulic test rig used in the side seal tests was modified to simulate a bottom seal arrangement, Figure 20. The seal seat was made with a curved depression 3/32 inch deep and 3 inches long measured parallel to the long dimension of the seal to represent a damaged seating surface which might be encountered in the field. The angle of the seal seat relative to the seal was similar to that of a field gate. Two all-rubber seal samples were available for test; each one was rectangular in section. One was made of stock with Type A Shore durometer hardness of 69; the other was made of stock with a hardness of 38.

Both seal samples were tested in the hydraulic rig at heads up to 195 feet of water. This test consisted of compressing the seal against the simulated gate seat and increasing the hydraulic head to 195 feet of water. Both seals appeared to seal satisfactorily, since there was no leakage at the depression in the gate seat. However, at heads of 55 feet or more, the soft rubber seal had a tendency to creep under the downstream clamp plate.

The principal test conducted on these two seal samples was to determine the force required to compress the seal. These data were desired for gate design purposes to assure sealing of depressions in the seal seat. This information was obtained on a Universal-type testing machine by determining the vertical force required to compress a 1-foot wide section of the seal against wet and dry seats. The wet seal data were obtained by submerging the simulated seal seat in a pan of water. A plot of the compression force, pounds per lineal foot of seal for wet and dry seat, is shown for both seal samples in Figure 20.

Conclusions

The rectangular-type radial gate bottom seal tested was satisfactory. The softer rubber material would probably form a more effective seal against surface irregularities in the seal seat. The tests

showed that for surface irregularities approximately 3/32 inch deep, the soft material would form a seal at an applied force of 50 pounds per lineal foot of seal; the harder material would require a force of 140 pounds per lineal foot.

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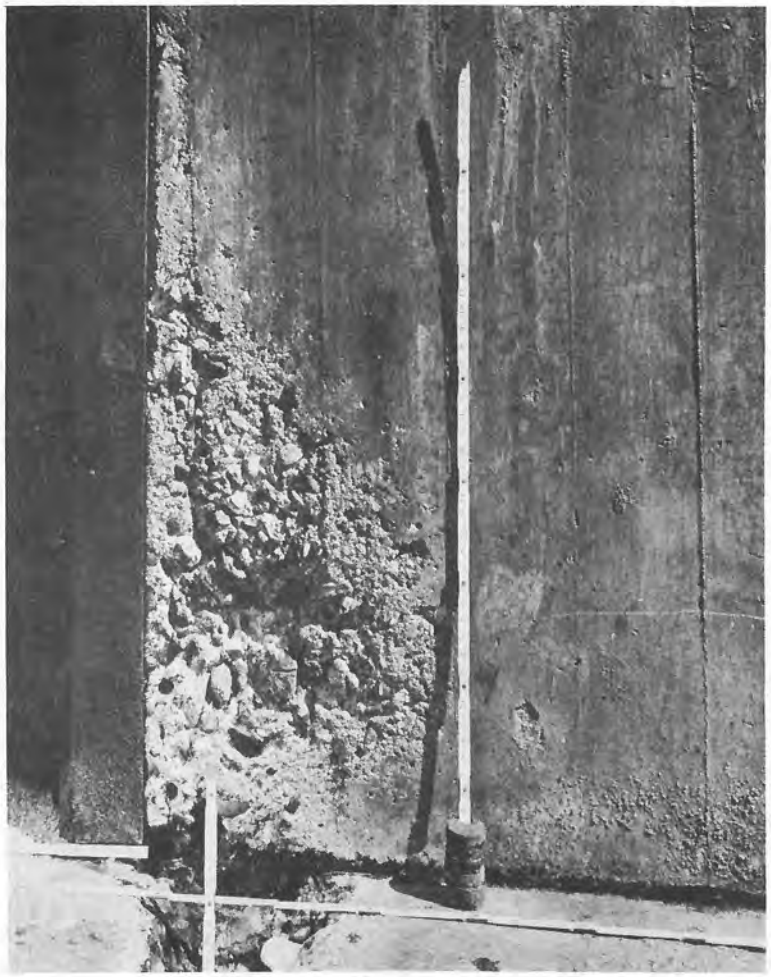
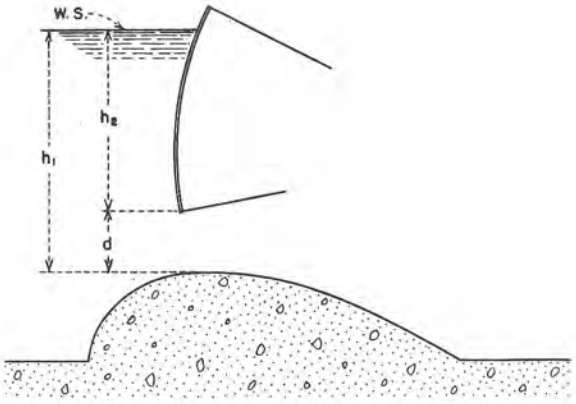
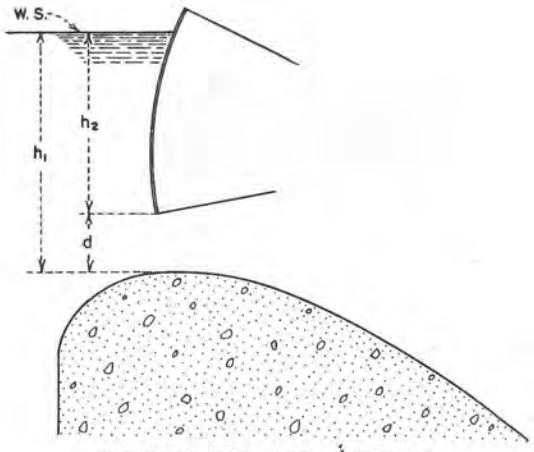


CAVITATION DAMAGE DOWNSTREAM
FROM GATE SLOTS
PARKER DAM SPILLWAY

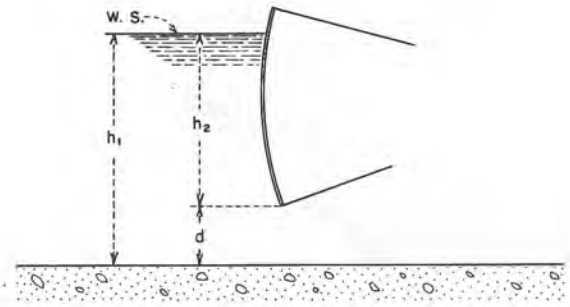
FIGURE 1



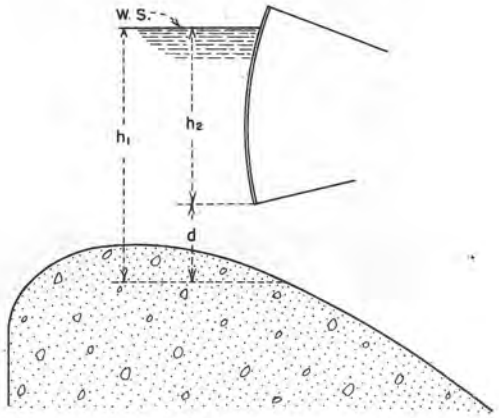
BULL LAKE AND GRANBY



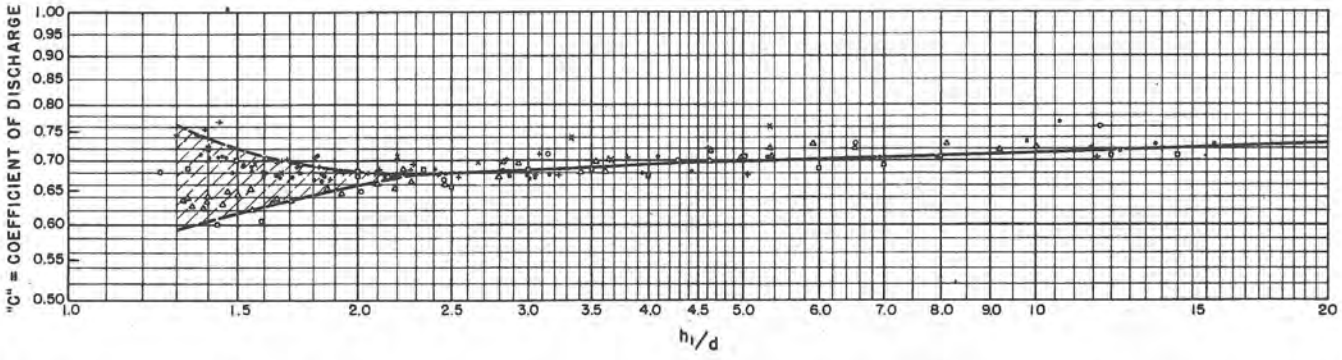
STEWART MTN. AND WHEELER



HORTON'S



CADDOA



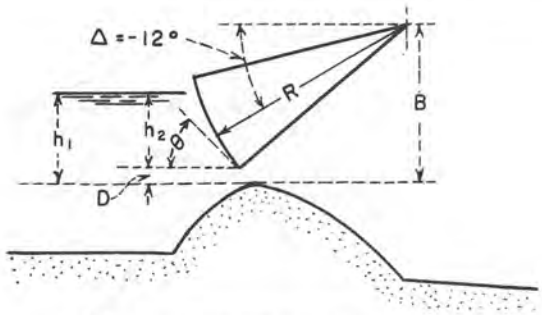
NOTE : The coefficient of discharge was calculated from the formula $Q = \frac{2}{3} C L \sqrt{2g} \, (h_1^{3/2} - h_2^{3/2})$.

- • Stewart Mountain Dam - Scale 1:50
- x Bull Lake Dam - Scale 1:30
- ▫ Wheeler Dam - Scale 1:36
- + Caddoa Dam - Scale 1:36
- ⊙ R. E. Horton's Experiments
- ▲ Granby Dam - Scale 1:48

COEFFICIENT OF DISCHARGE
RADIAL GATES

FIGURE 2

X-D-441



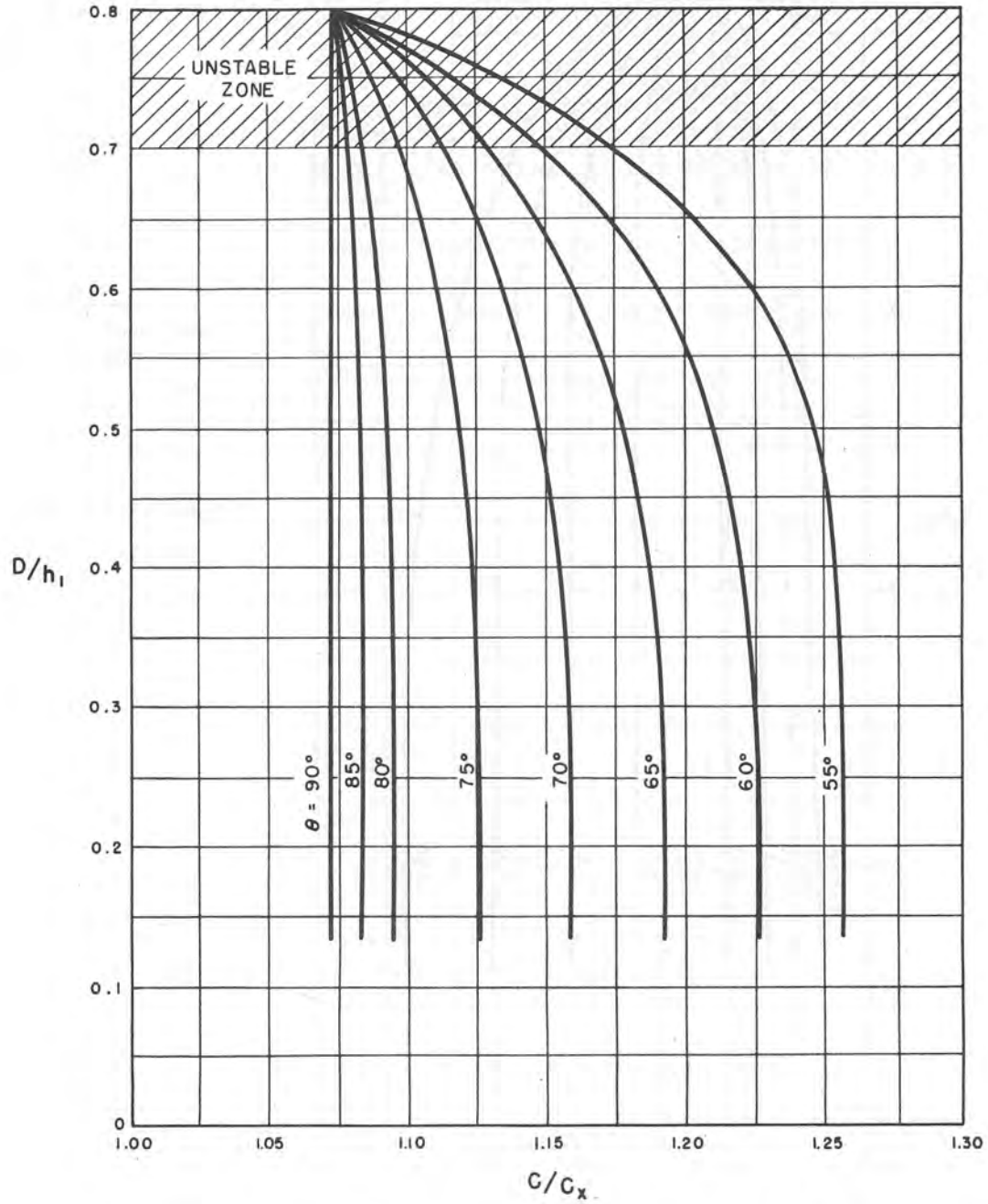
EQUATION FOR DISCHARGE

$$Q = CL(h_1^{3/2} - h_2^{3/2})$$

C_x = Free flow coefficient for a given head

C = Orifice coefficient at same head

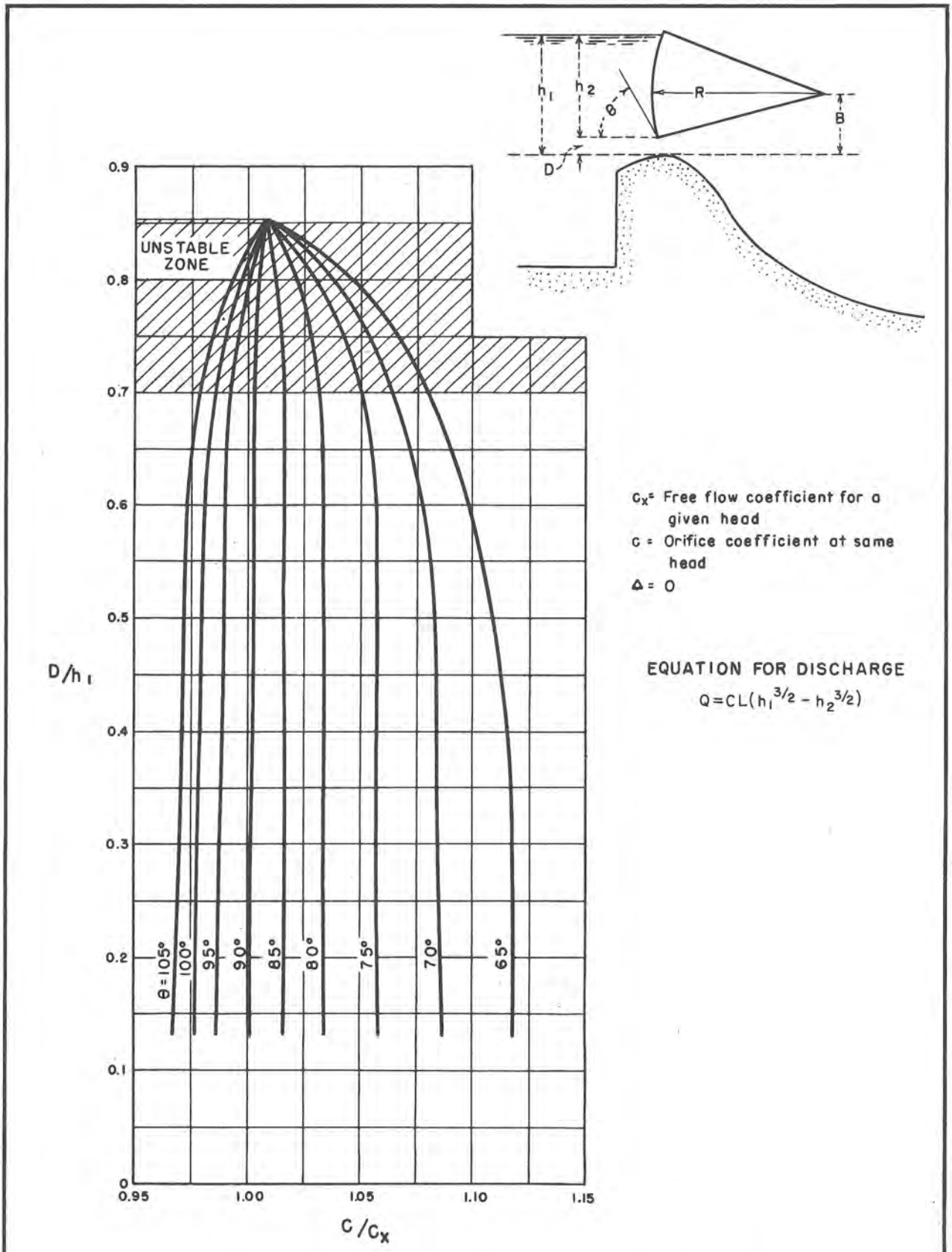
Δ = -12°



DISCHARGE COEFFICIENTS FOR RADIAL GATES

FIGURE 3

608



C_x = Free flow coefficient for a given head

C = Orifice coefficient at same head

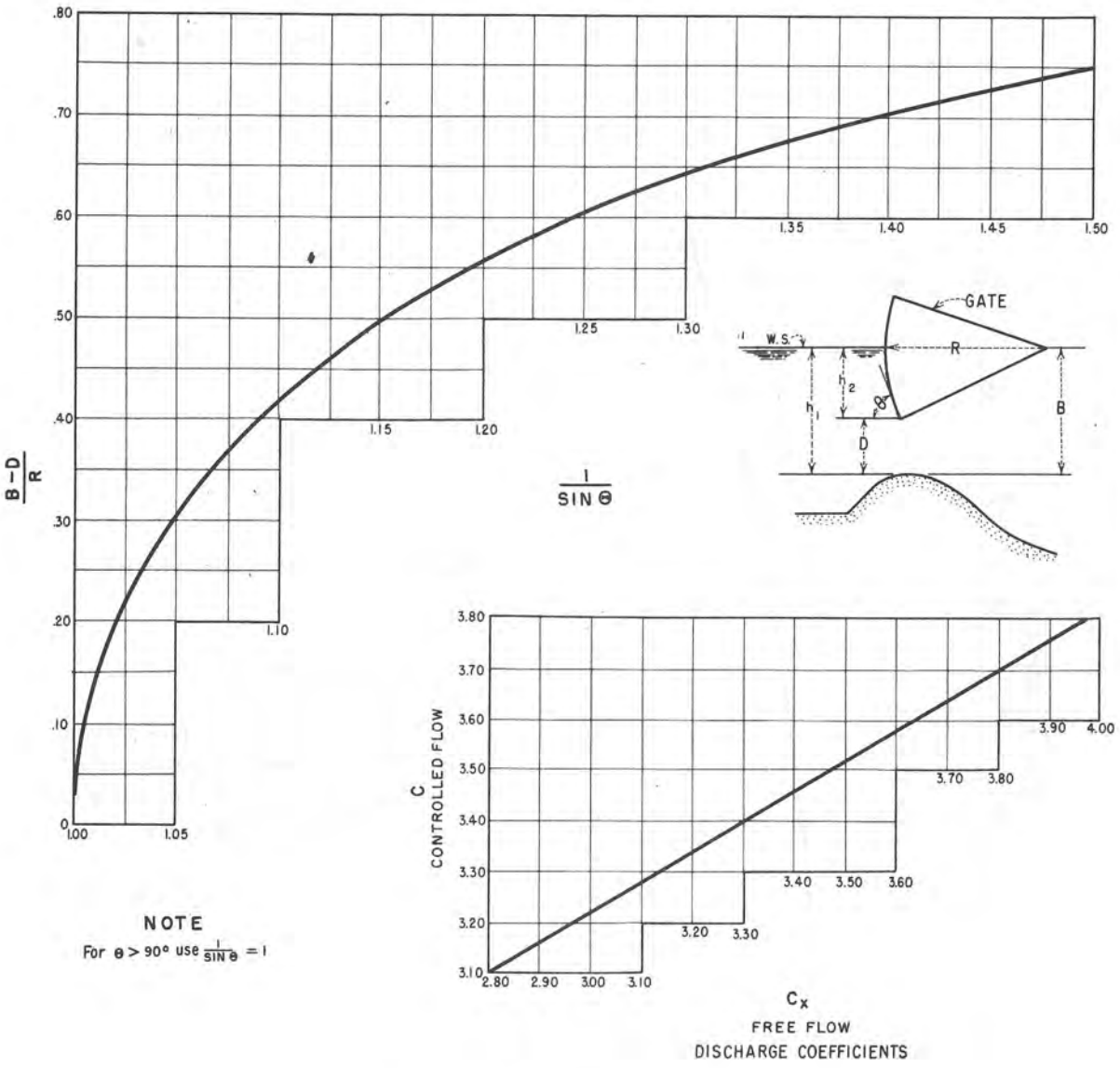
Δ = 0

EQUATION FOR DISCHARGE

$$Q = CL(h_1^{3/2} - h_2^{3/2})$$

DISCHARGE COEFFICIENTS FOR RADIAL GATES

FIGURE 4



NOTE

For $\theta > 90°$ use $\frac{1}{\sin\theta} = 1$

EQUATION FOR DISCHARGE

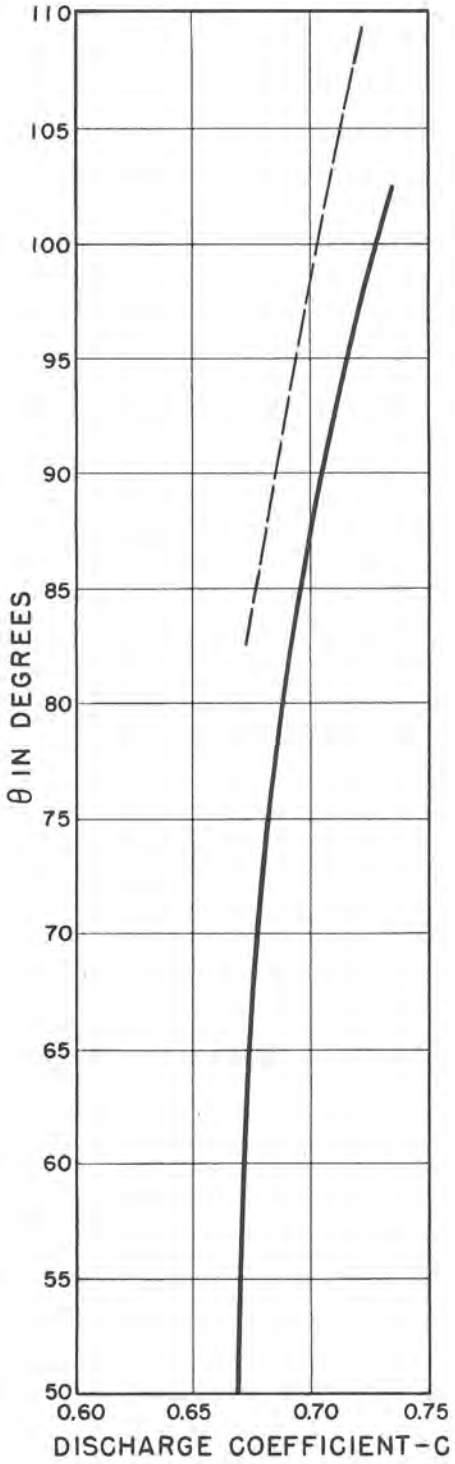
$$Q = CL\frac{1}{\sin\theta}\left(h_1^{3/2} - h_2^{3/2}\right)$$

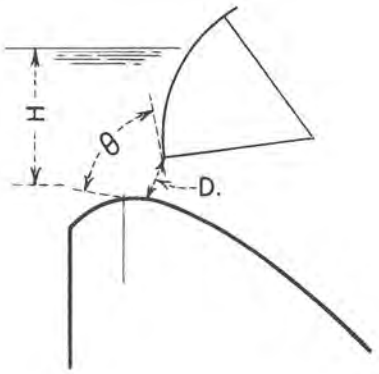
L = Length of crest

DISCHARGE UNDER A RADIAL GATE

FIGURE 5

608





EQUATION FOR DISCHARGE

$Q = CDL\sqrt{2gH}$

D = Net gate opening

L = Crest width

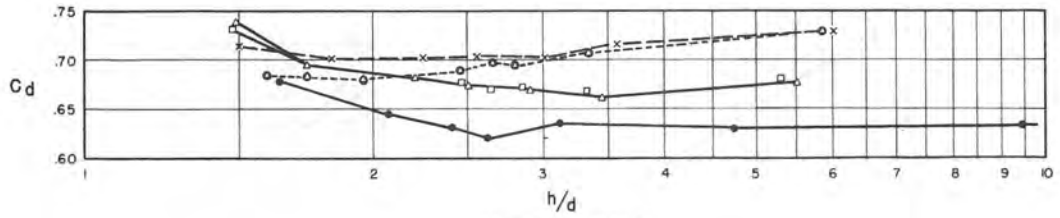
H = Head to center of gate opening

For C use dashed line when gate seats on crest and solid line when gate seats below crest.

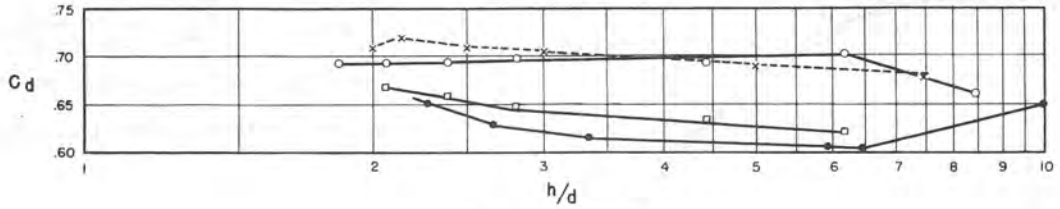
DISCHARGE UNDER A RADIAL GATE

FIGURE 6

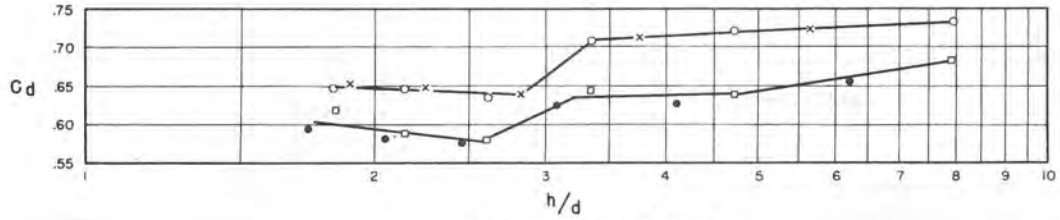
608



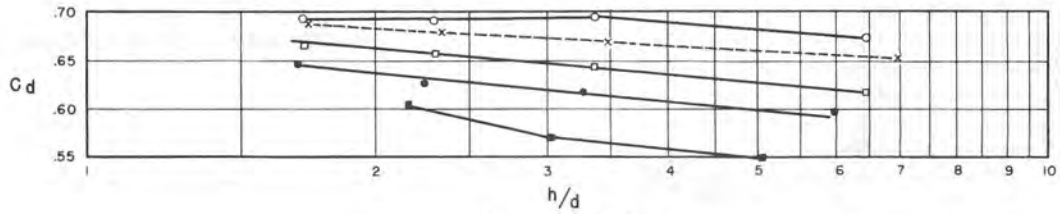
(A) ROSS DAM



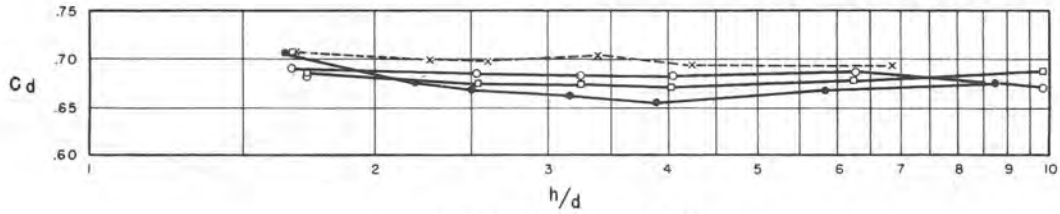
(B) ALTUS DAM



(C) AMERICAN FALLS DAM



(D) BHAKRA DAM



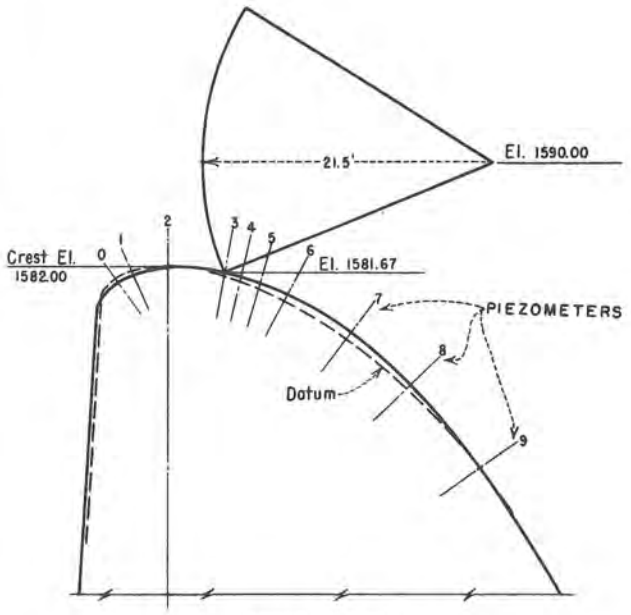
(E) CANYON FERRY DAM

EXPLANATION OF SYMBOLS

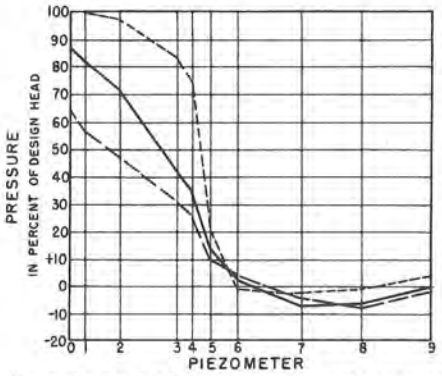
C_d	Coefficient of discharge in $Q = \frac{2}{3} C_d L (H^{3/2} - h^{3/2}) \sqrt{2g}$
Q	Discharge in cfs
L	Spillway width
H	Vertical distance from gate seat to reservoir elevation
h	Vertical distance from gate lip to reservoir elevation
d	Vertical distance from gate seat to gate lip
■	Gate seat 2.43 ft. below crest, on downstream side
●	Gate seat 12 inches below crest, on downstream side
□	Gate seat 6 inches below crest, on downstream side
△	Gate seat 4 inches below crest, on downstream side
×	Gate seat on crest
○	Gate seat 6 inches below crest, on upstream side

EFFECT OF GATE POSITION ON DISCHARGE COEFFICIENT

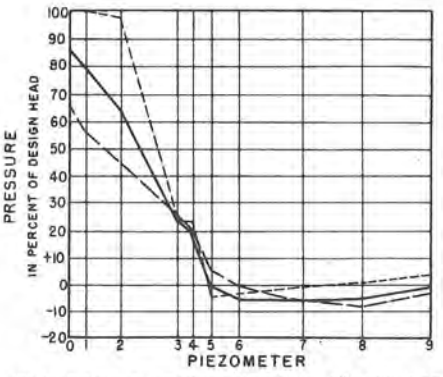
FIGURE 7



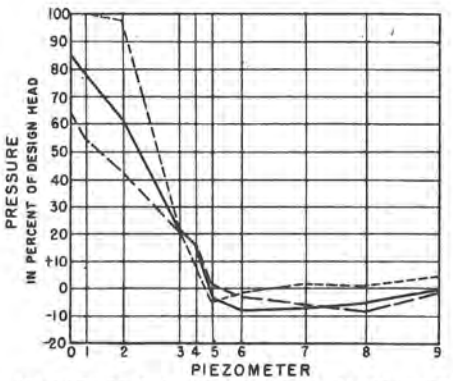
CREST PROFILE



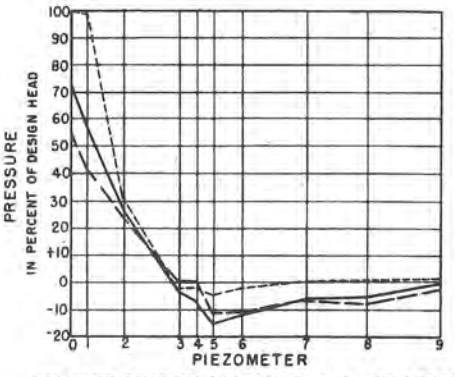
(1) GATE SEAT AT PIEZOMETER 5, 12" BELOW CREST



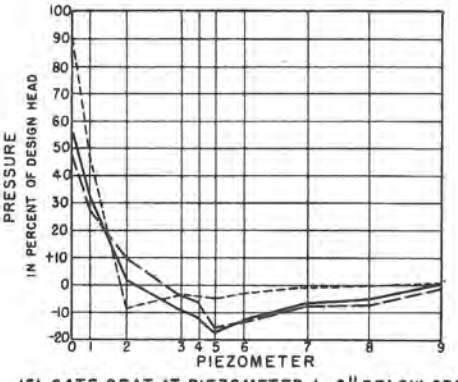
(2) GATE SEAT AT PIEZOMETER 4, 6" BELOW CREST



(3) GATE SEAT AT PIEZOMETER 3, 4" BELOW CREST



(4) GATE SEAT AT PIEZOMETER 2, ON CREST



(5) GATE SEAT AT PIEZOMETER 1, 6" BELOW CREST

NOTES

Head and gate openings measured vertically above crest

---------- Gate open 5.5 % of design head

——————— Gate open 33.3 % of design head

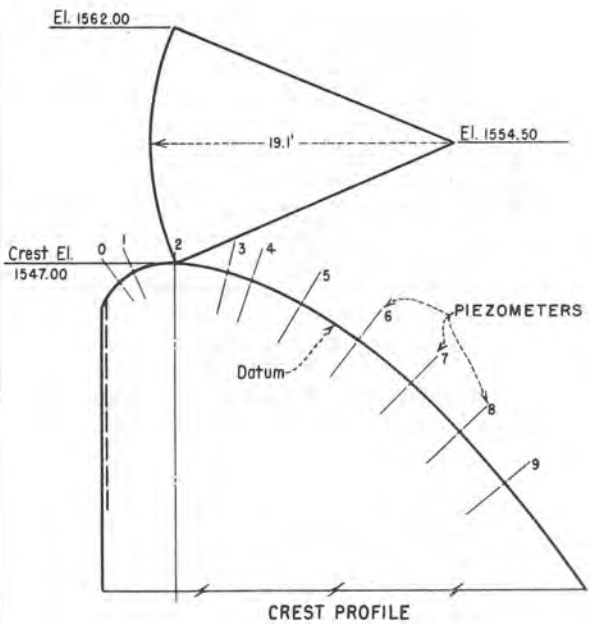
— — — — — Gate open 55.6 % of design head

EFFECT OF GATE POSITION ON PRESSURE DISTRIBUTION

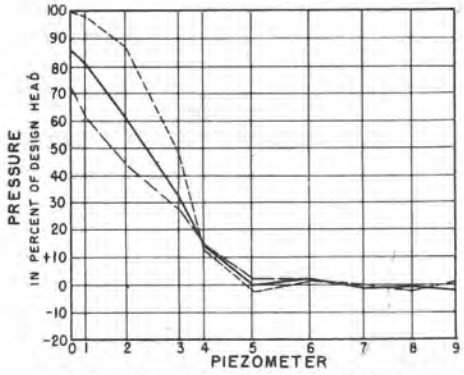
ROSS DAM CREST

FIGURE 8

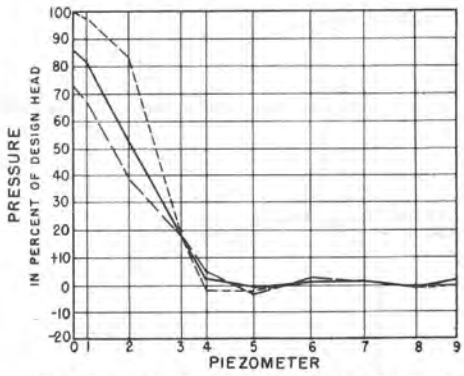
608



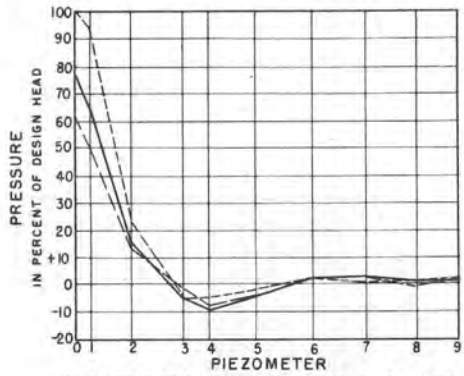
CREST PROFILE



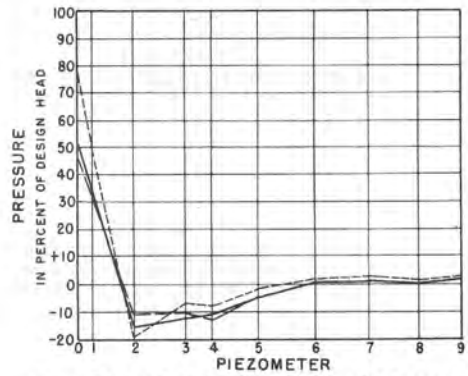
(1) GATE SEAT AT PIEZOMETER 4, 12" BELOW CREST



(2) GATE SEAT AT PIEZOMETER 3, 6" BELOW CREST



(3) GATE SEAT AT PIEZOMETER 2, ON CREST



(4) GATE SEAT AT PIEZOMETER 1, 6" BELOW CREST

NOTES

Head and gate openings measured vertically above crest

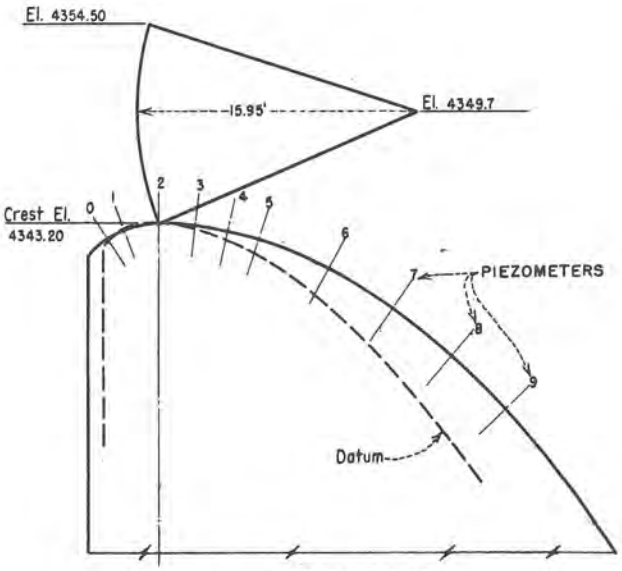
---------- Gate open 13.9 % of design head

——————— Gate open 33.3 % of design head

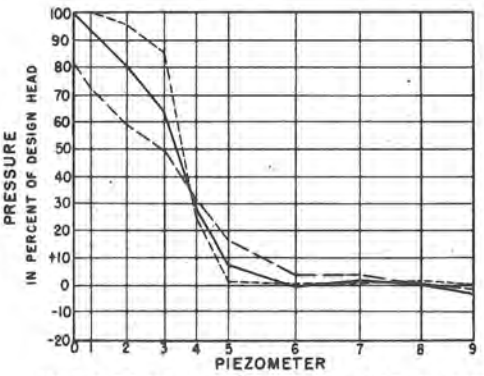
— — — — — Gate open 46.7 % of design head

EFFECT OF GATE POSITION ON PRESSURE DISTRIBUTION
ALTUS DAM CREST
FIGURE 9

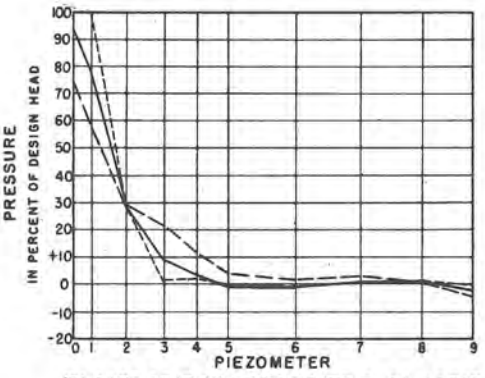
608



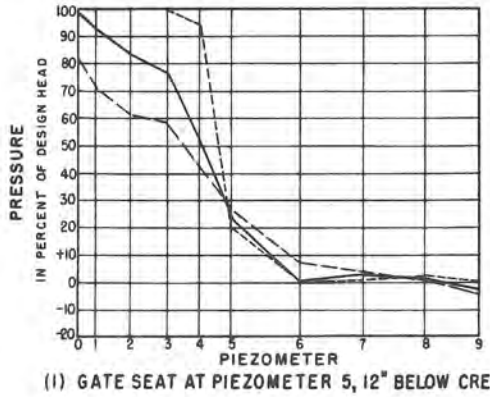
CREST PROFILE



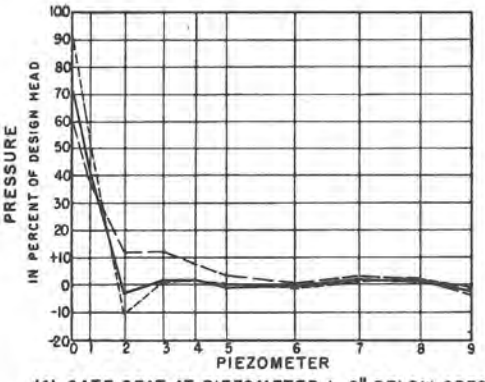
(2) GATE SEAT AT PIEZOMETER 4, 6" BELOW CREST



(3) GATE SEAT AT PIEZOMETER 2, ON CREST



(1) GATE SEAT AT PIEZOMETER 5, 12" BELOW CREST



(4) GATE SEAT AT PIEZOMETER 1, 6" BELOW CREST

NOTES

Head and gate openings measured vertically above crest

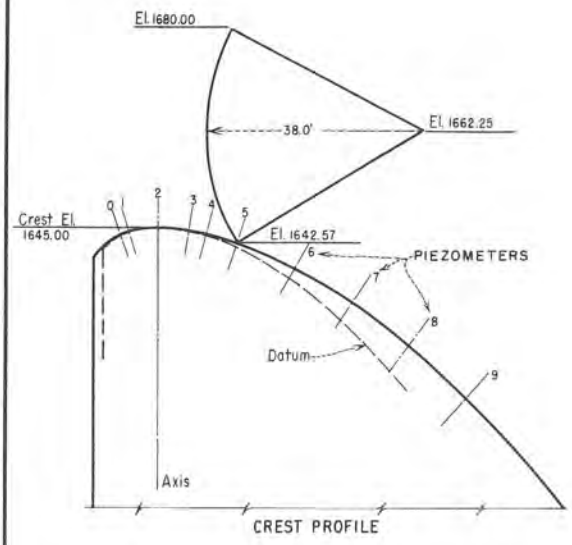
----------Gate open 8.8 % of design head

——————Gate open 26.6 % of design head

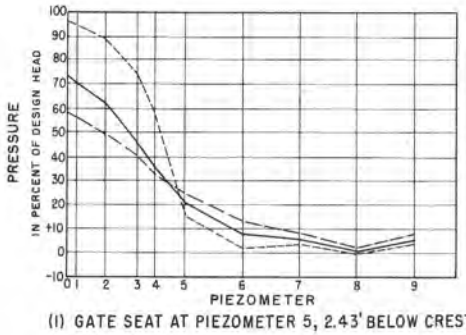
— — — — — Gate open 52.9 % of design head

EFFECT OF GATE POSITION ON PRESSURE DISTRIBUTION
AMERICAN FALLS DAM CREST
FIGURE 10

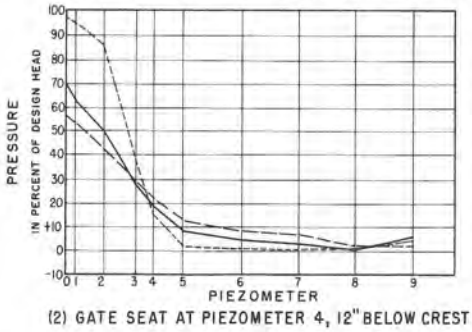
608



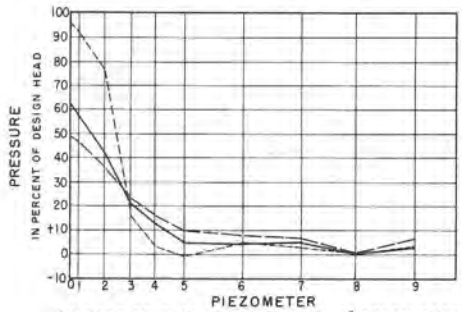
CREST PROFILE



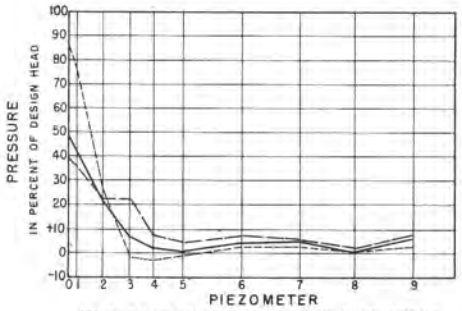
(1) GATE SEAT AT PIEZOMETER 5, 2.43' BELOW CREST



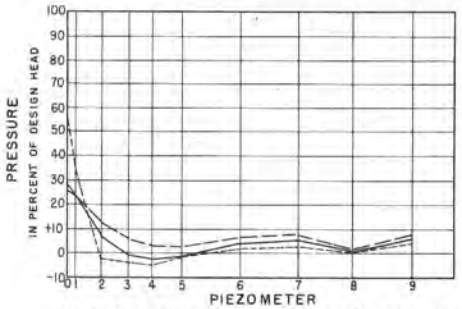
(2) GATE SEAT AT PIEZOMETER 4, 12" BELOW CREST



(3) GATE SEAT AT PIEZOMETER 3, 6" BELOW CREST



(4) GATE SEAT AT PIEZOMETER 2, ON CREST



(5) GATE SEAT AT PIEZOMETER 1, 6" BELOW CREST

NOTES

Head and gate openings measured vertically above crest

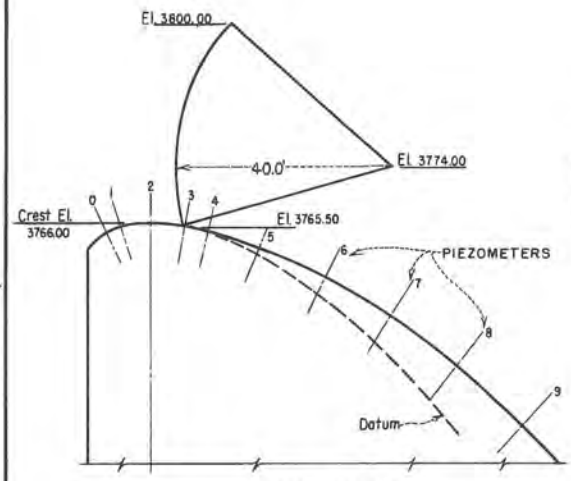
Gate open 14.3 % of design head

Gate open 42.8 % of design head

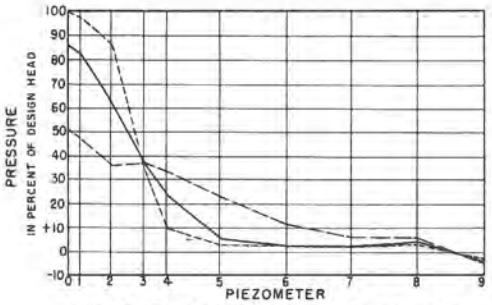
Gate open 57.2 % of design head

EFFECT OF GATE POSITION ON PRESSURE DISTRIBUTION
BHAKRA DAM CREST
FIGURE 11

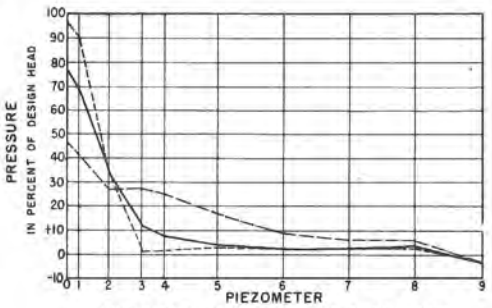
608



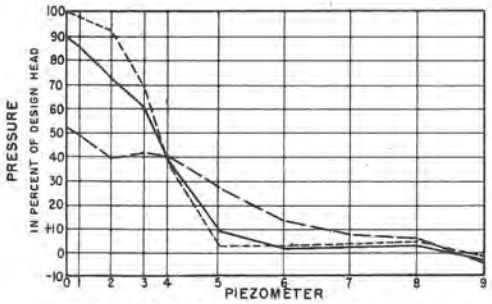
CREST PROFILE



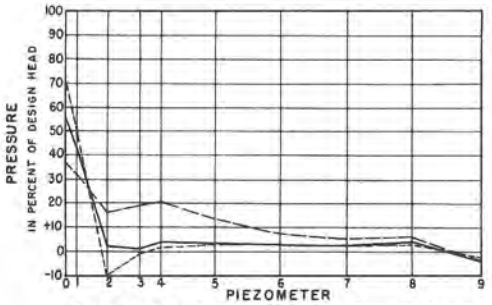
(2) GATE SEAT AT PIEZOMETER 3, 6" BELOW CREST



(3) GATE SEAT AT PIEZOMETER 2, ON CREST



(1) GATE SEAT AT PIEZOMETER 4, 12" BELOW CREST



(4) GATE SEAT AT PIEZOMETER 1, 6" BELOW CREST

NOTES

Head and gate openings measured vertically above crest.

---------- Gate open 8.8% of design head

———— Gate open 23.5% of design head

— — — — Gate open 58.8 % of design head

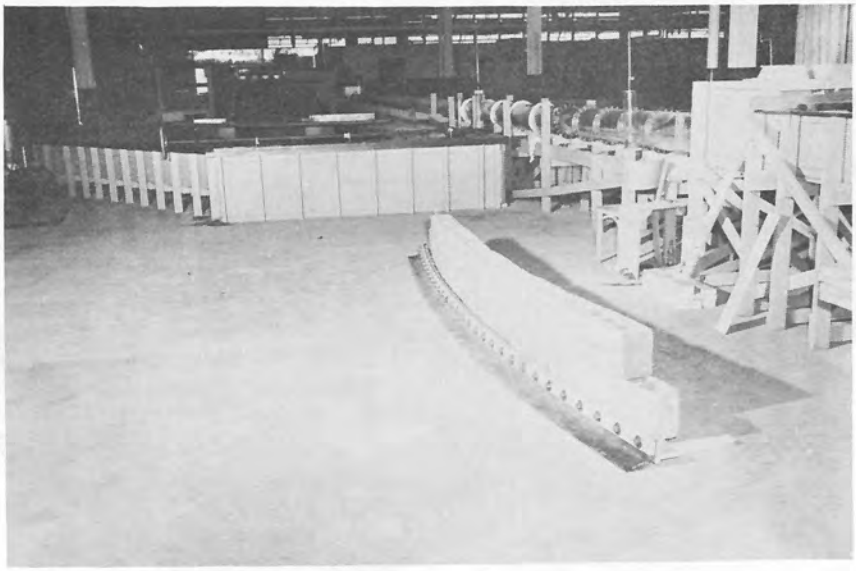
EFFECT OF GATE POSITION ON PRESSURE DISTRIBUTION

CANYON FERRY DAM CREST

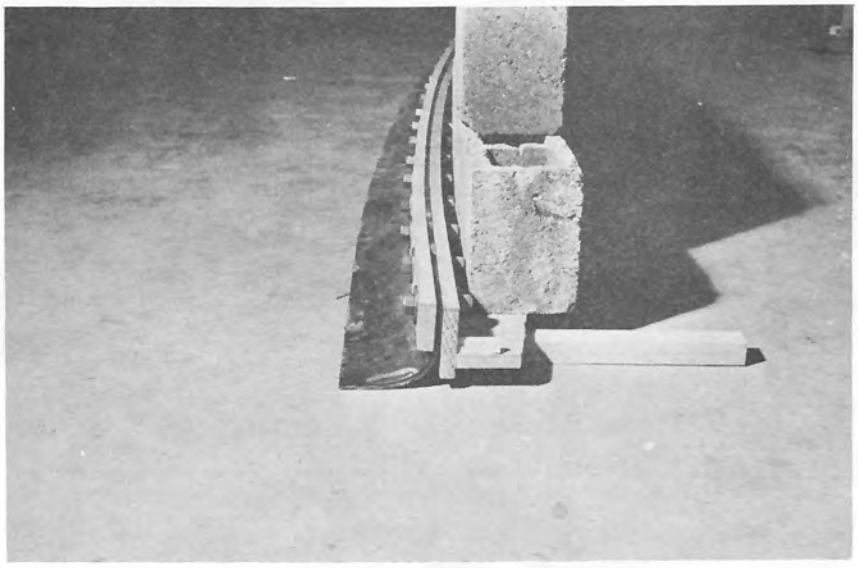
FIGURE 12

608

From HYD-323



(A) General view of the 3/8 x 8 inch x 15 foot long belting seal bolted to a 40-foot radius.



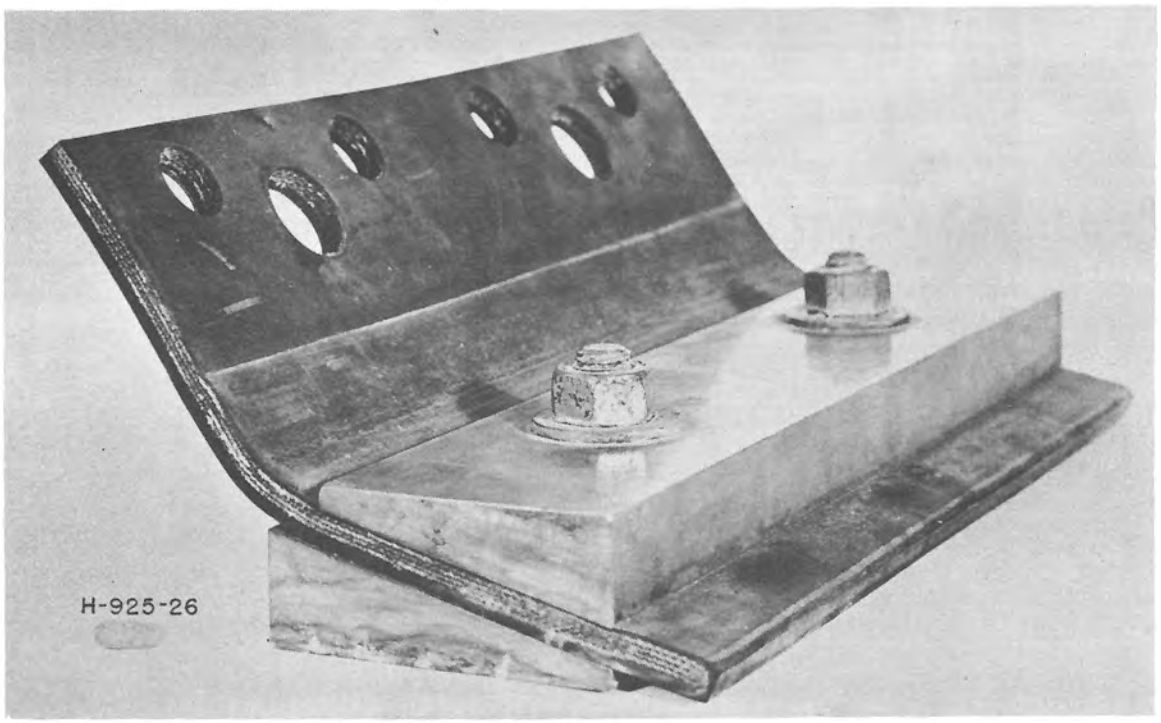
(B) Close-up view of the above assembly.

FIGURE 13

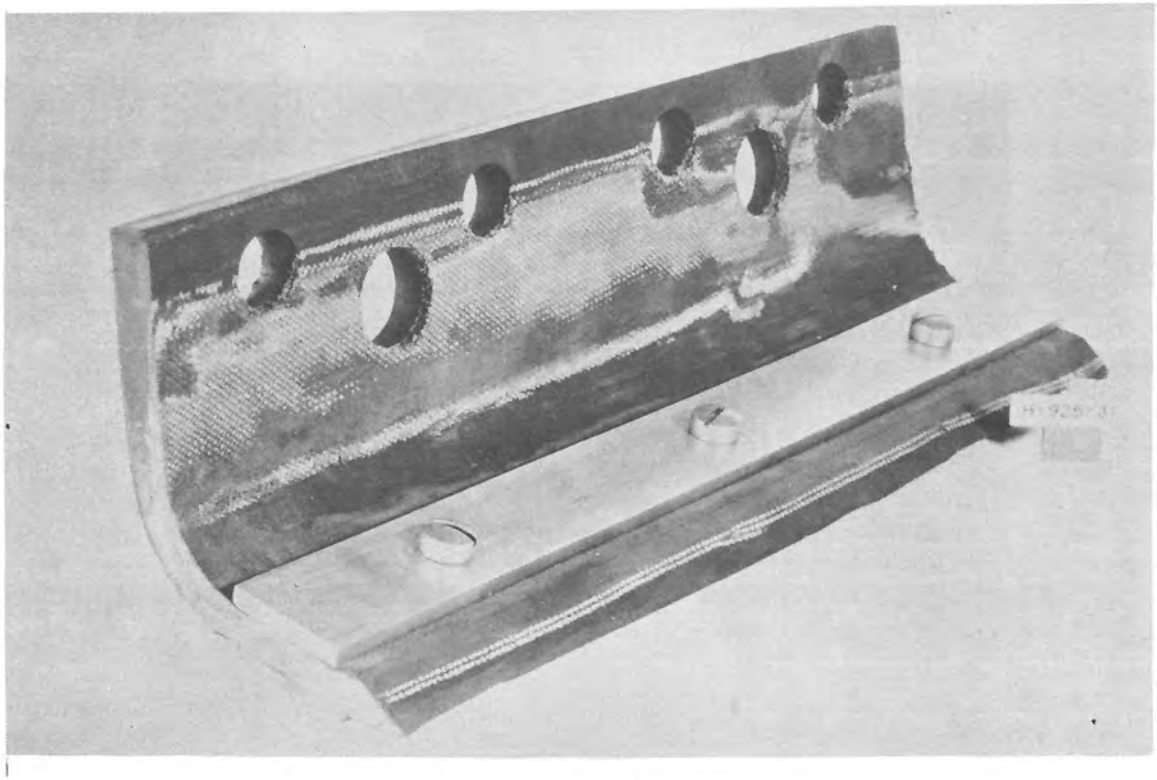
RADIAL GATE SEAL TESTS

Wooden Mock-up of Rubber Belting Side Seal without Brass Shoes

From HYD-323



(A) View of the rubber belting seal with brass shoes.



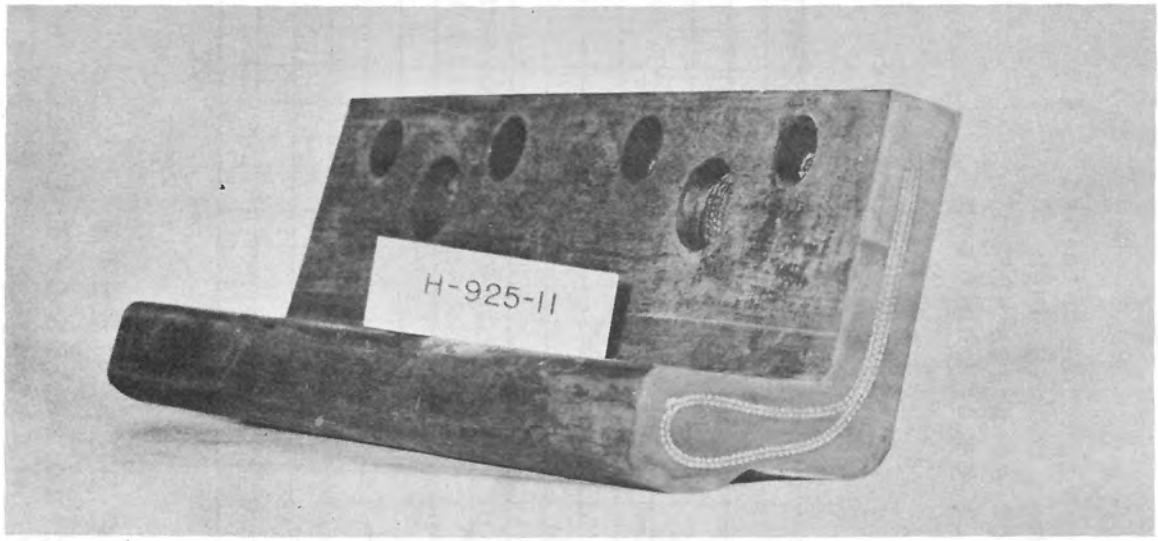
(B) View of the belt type, molded angle seal, with brass shoe, cut from a fabric reinforced angle seal shown on Figure 15A.

FIGURE 14

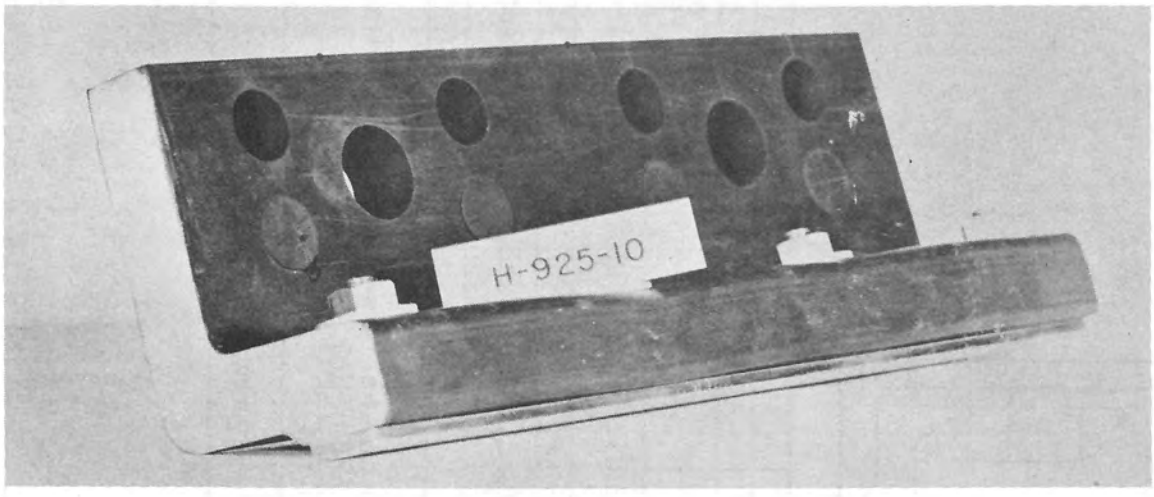
RADIAL GATE SEAL TESTS

Belt Type Side Seals with Metal Shoes

From HYD-323



(A) View of the angle seal with fabric reinforcement.



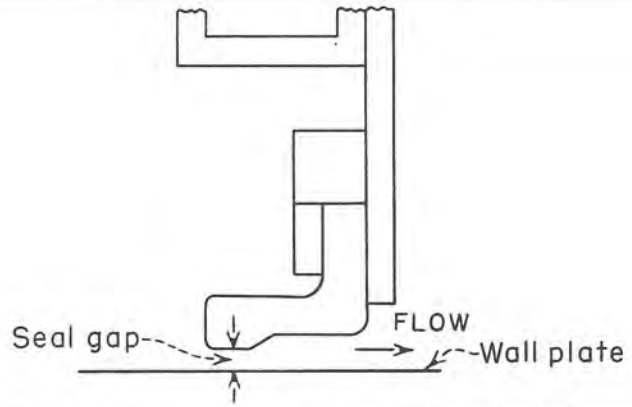
(B) View of the all-rubber angle seal with a brass bar added to reduce frictional drag on wall plate.

FIGURE 15

RADIAL GATE SEAL TESTS

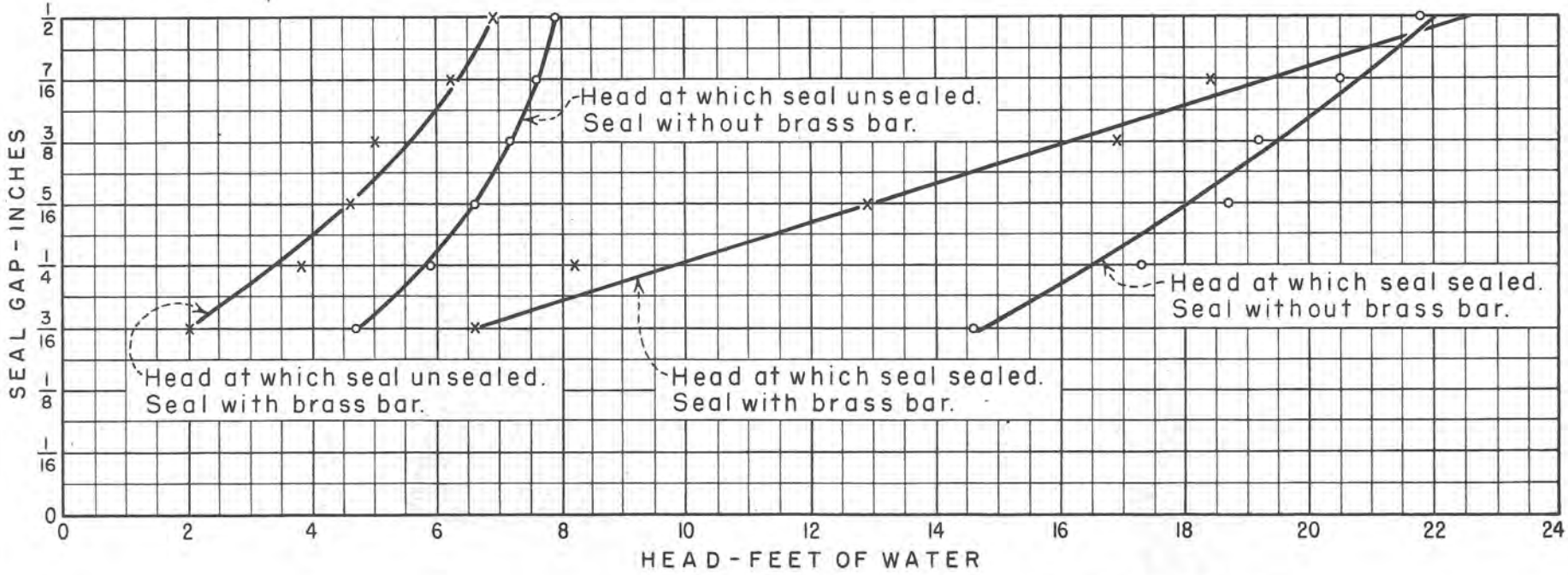
Views of the Molded Angle Side Seal with Fabric Reinforcement and a Brass Bar

FIGURE 16



NOTES

1. No head readings could be obtained at seal gaps less than $\frac{3}{16}$-inch.
2. Head values varied minus 40% at $\frac{3}{16}$-inch to minus 10% at $\frac{1}{2}$-inch gap.

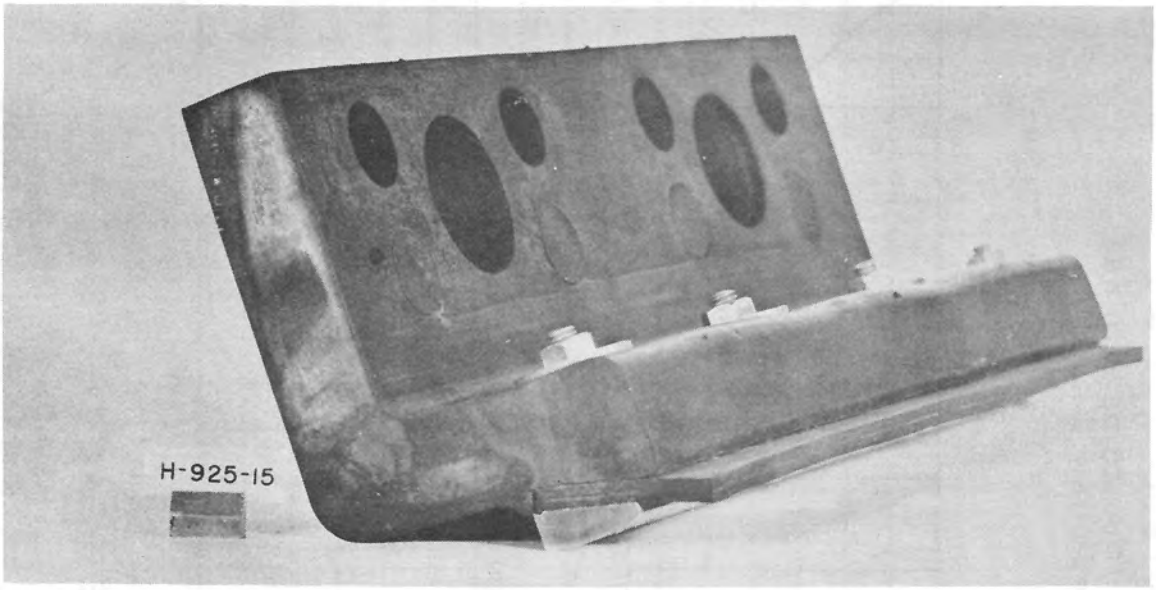


RADIAL GATE SEAL TESTS

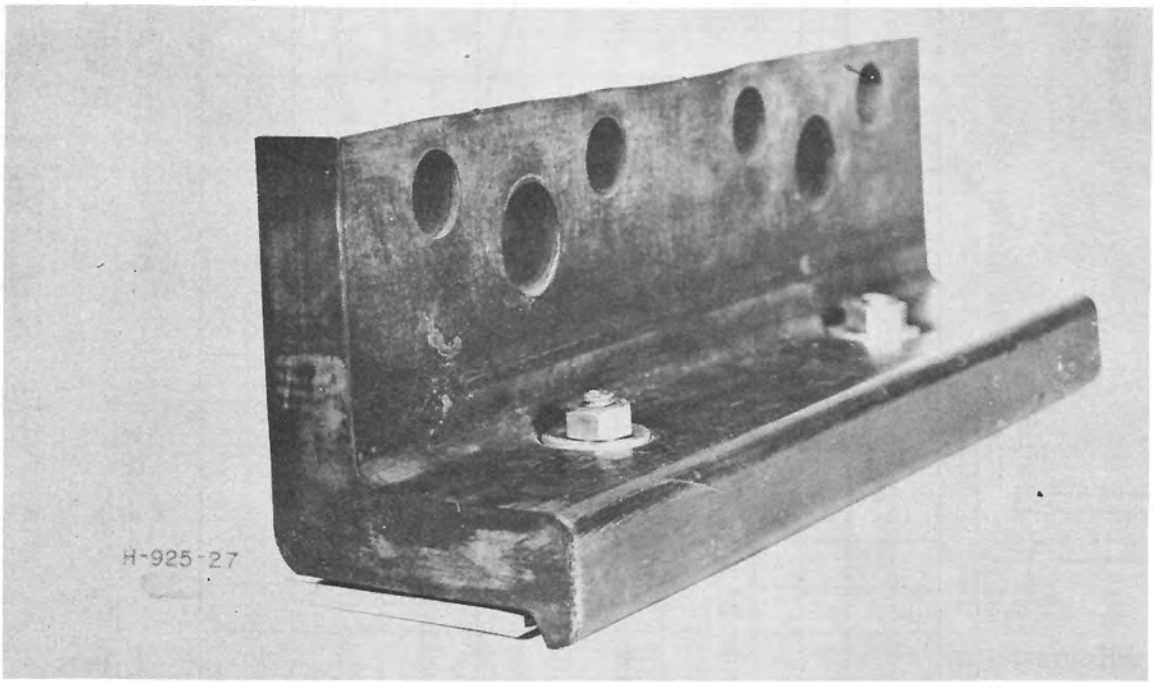
SEALING AND UNSEALING HEADS OF THE ALL RUBBER ANGLE SIDE SEAL WITH AND WITHOUT BRASS BAR

415

From HYD 323



(A) View of the angle seal with a brass bar plus a rubber sealing flap.



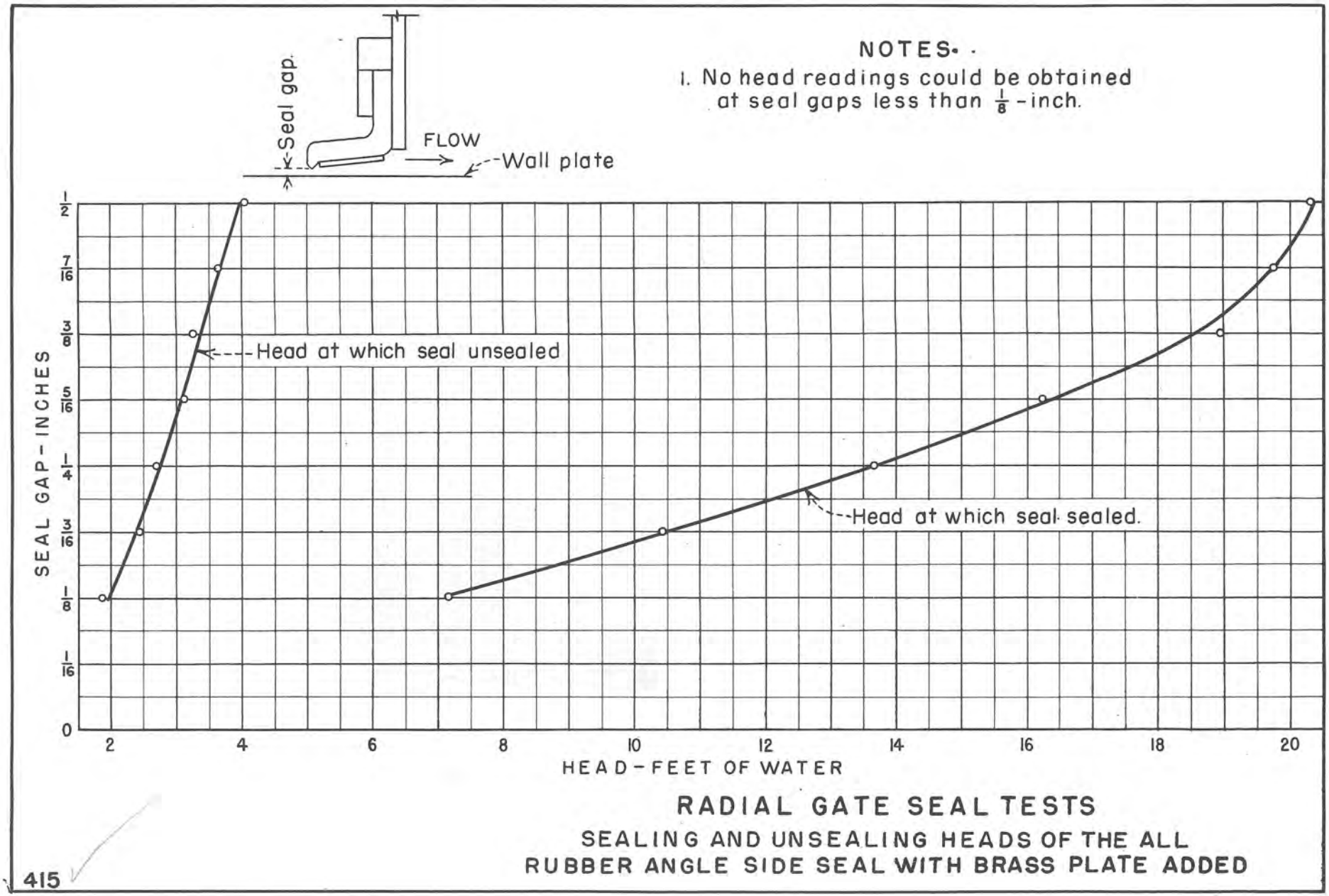
(B) View of the angle seal with rubber removed from the lower leg and a brass plate added.

FIGURE 17

RADIAL GATE SEAL TESTS

Views of the Angle Side Seal with a Brass Bar plus a Rubber Sealing Flap and with a Brass Plate.

FIGURE 18



RADIAL GATE SEAL TESTS

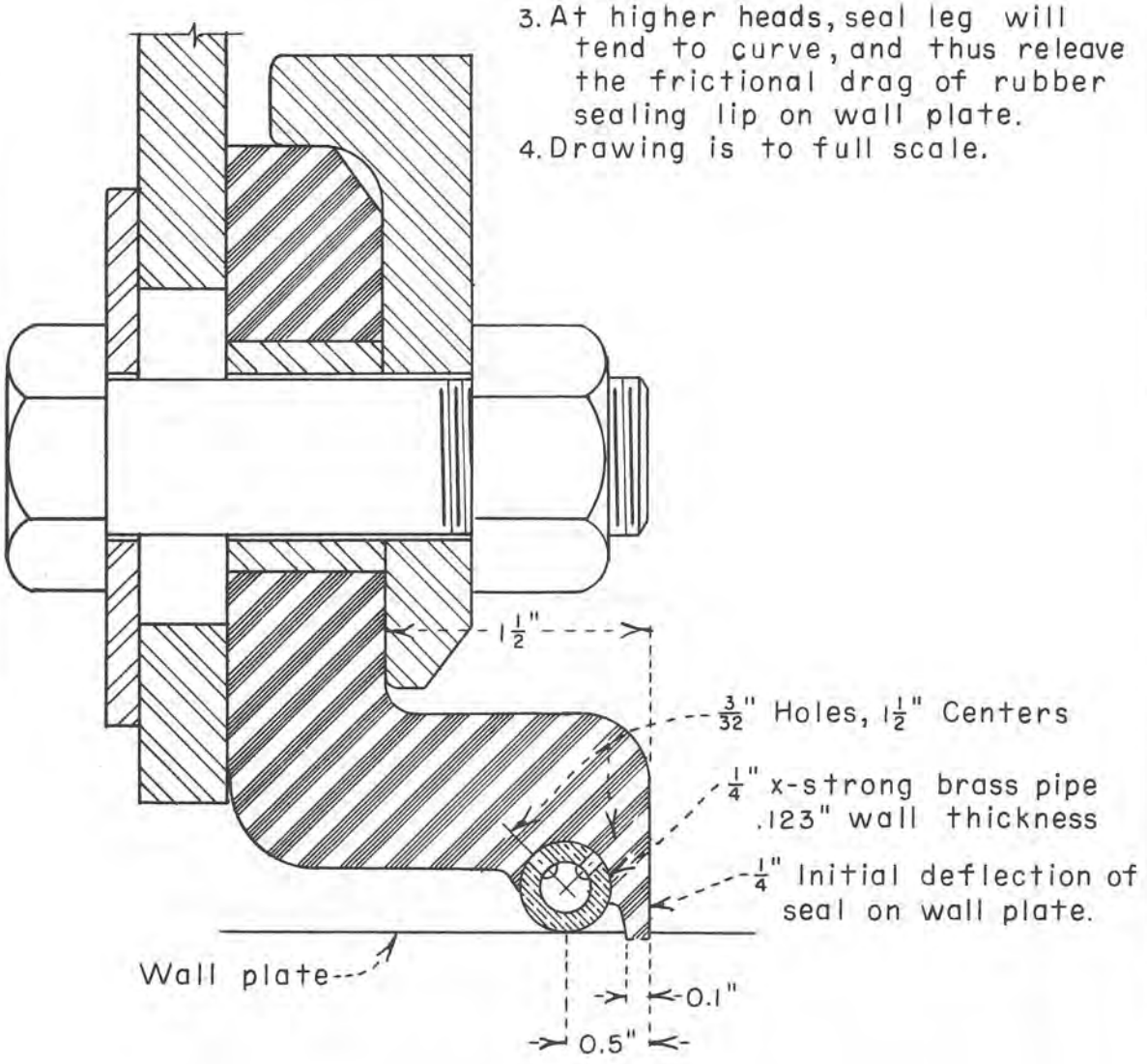
SEALING AND UNSEALING HEADS OF THE ALL RUBBER ANGLE SIDE SEAL WITH BRASS PLATE ADDED

415

FIGURE 19

NOTES

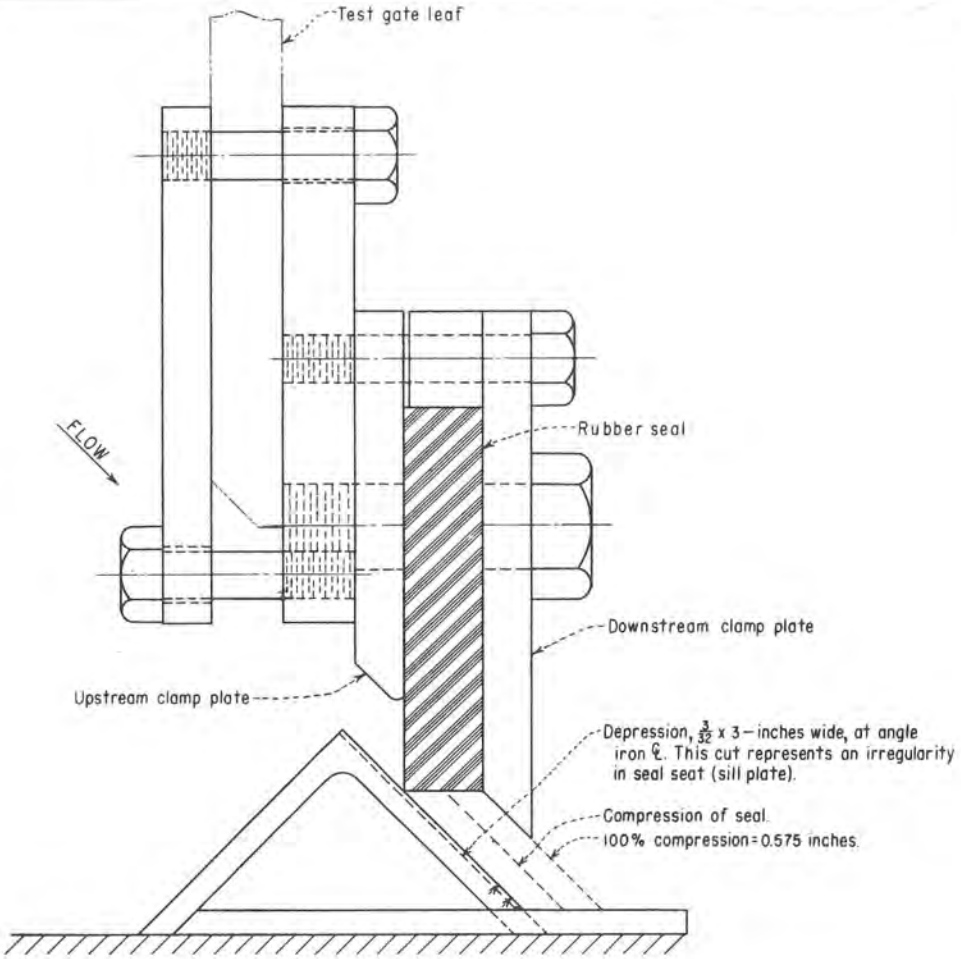
1. Approximately one-third of seal water load across the $1\frac{1}{2}$" dimension is carried by the gate; the remainder of water load is carried to the wall plate.
2. Brass pipe may be slightly curved during assembly to fit gate curvature.
3. At higher heads, seal leg will tend to curve, and thus releave the frictional drag of rubber sealing lip on wall plate.
4. Drawing is to full scale.



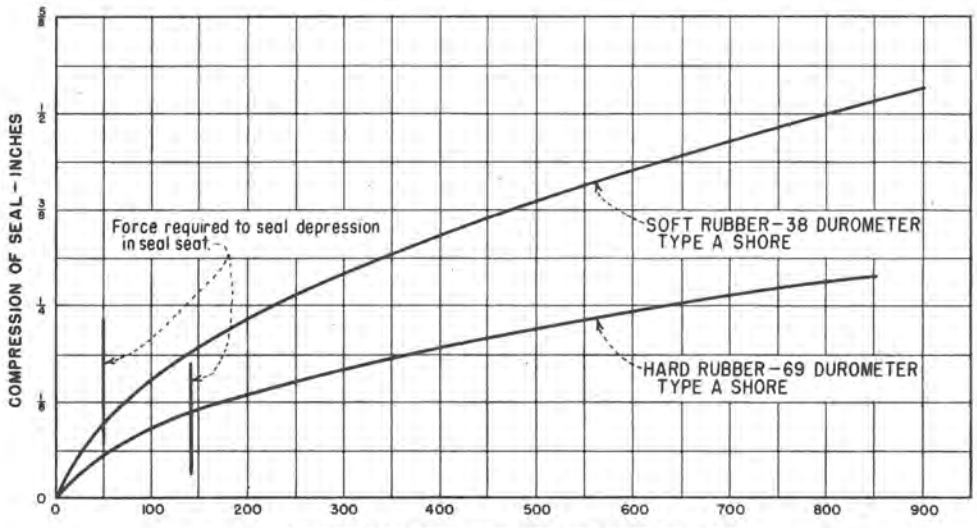
RADIAL GATE SEAL TESTS

PROPOSED SIDE SEAL WITH A BRASS PIPE
AND A RUBBER SEALING LIP

415


Test gate leaf
FLOW
Rubber seal
Downstream clamp plate
Upstream clamp plate
Depression, 3/32 x 3 – inches wide, at angle iron ℄. This cut represents an irregularity in seal seat (sill plate).
Compression of seal.
100% compression = 0.575 inches.

SIDE VIEW – ASSEMBLY – 12 INCHES WIDE



FORCE REQUIRED TO COMPRESS RADIAL GATE BOTTOM SEAL

RADIAL GATE SEAL TESTS

ARRANGEMENT FOR HYDRAULIC AND COMPRESSION TESTS OF BOTTOM SEAL

FIGURE 20

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